FIRE-BIRD user manual – GIS-based habitat suitability model application tools to inform conservation planning and land management

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1. INTRODUCTION

To conserve and promote biological diversity, land managers must identify suitable habitat for species of conservation concern. Managers can then restrict potentially detrimental activities (e.g., resource extraction, development) to areas of lower habitat suitability, and target beneficial activities (e.g., restoration, conservation) where habitat suitability is higher (Barrows et al. 2008, Guisan et al. 2013, Latif et al. 2013, Brambilla and Saporetti 2014, Latif et al. 2015). Land managers often rely on informal methods for identifying habitat, e.g., verbal descriptions based on expert knowledge, which have unknown reliability and limited ability to reflect complex habitat associations. In contrast, habitat suitability models (a.k.a. species distribution models; hereafter *habitat models*) rigorously quantify suitable habitat using data-driven algorithms capable of representing complex relationships with multiple environmental attributes (Guisan and Thuiller 2005, Elith and Leathwick 2009, Franklin 2009, Guisan et al. 2013). Such information can enhance planning effectiveness and is needed to make management decisions robust to legal scrutiny (e.g., Defenders of Wildlife vs. Sally Jewell, U.S. Department of the Interior and Daniel M. Ashe, U.S. Fish and Wildlife Service, 4 Apr 2016, Case 9:14-cv-00246-DLC, Document 108). Despite numerous publications describing new models, however, management planners lack technical expertise necessary to apply these models to their project areas, and online tools for non-experts to develop their own models are limited (reviewed by Guisan et al. 2013).

Managers currently rely heavily on geographic information systems (GIS) technology to develop and inform their decisions and planning. In particular, by providing a powerful set of mapping and spatial analysis tools through a relatively user friendly graphic interface, ArcGIS (ESRI 2015) has become the most widespread GIS software used by managers. Because much of the planning process takes place in an ArcGIS environment, managers must at some point translate habitat information into map layer(s) viewable in ArcGIS. Habitat models are fundamentally statistical entities developed using statistical software packages (e.g., R; *ref*) whose outputs do not readily interface with ArcGIS. Analysts often develop habitat models, however, with remotely sensed environmental data to facilitate translation of model predictions into habitat maps. Recent versions of ArcGIS software increasingly allow users to develop custom tools to generate and process spatial data layers. We leverage these new features to develop ArcGIS tools that facilitate translation of statistical model predictions into habitat maps by users with minimal technical expertise.

We have developed a series of ArcGIS tools for applying habitat models for disturbance-associated woodpeckers to guide management of conifer forests in western North America. Large-scale disturbances, especially wildfire and bark beetle outbreaks, strongly influence vegetation structure and composition in these forests. Anthropogenic land use and climate change have altered disturbance timing and severity, along with associated structural and wildlife habitat features (Whitlock et al. 2003, Schoennagel et al. 2004, Hessburg et al. 2007, Franklin and Johnson 2012, Fulé et al. 2012, Hessburg et al. 2015). In particular, many woodpeckers associate with and benefit from habitats generated and maintained by large-scale disturbance (Russell et al. 2007, Saab et al. 2009, Wightman et al. 2010, Latif et al. 2013, Saab et al. 2014). State and federal agencies are concerned with conservation of these woodpeckers and have legal requirements to document the effects of management actions on their habitats and populations. Forest managers must therefore consider the trade-offs between land uses and wildlife habitat conservation in their planning documents. In recently disturbed forests, managers are mainly concerned with meeting often conflicting objectives of conserving habitat while also providing opportunity for economic recovery of timber resources through salvage logging. As new disturbances occur, model application tools targeting disturbed habitats could facilitate rapid identification of suitable habitat for woodpeckers and other disturbance-associated species. Additionally, tools in green forest could help identify conditions maintained by disturbance processes, such as canopy mosaics and ponderosa pine, with which other species associate (e.g., White-headed Woodpecker [*Picoides albolarvatus*]), and that are targeted by large-scale dry forest restoration and fuels reduction projects (e.g., CFLRPs; Mellen-McLean et al. 2013, Mellen-McLean et al. 2015).

In this manual, we summarize the ecological basis and applicability of habitat suitability models for which we have produced ArcGIS application tools. We then provide step-by-step instructions for implementing tools made available here. These currently consist of tools that quantify post-wildfire habitat for Black-backed Woodpecker (*Picoides arcticus*), White-headed Woodpecker, and Hairy Woodpecker (*Picoides villosus*). An additional tool quantifies green forest habitat for White-headed Woodpecker maintained by disturbance processes. Finally, we describe how mapped predictions can be interpreted to appropriately inform forest management at the project scale.

2. CONCEPTUAL BASIS FOR HSI MODELS

2.1 Black-backed Woodpeckers in burned forests

Latif et al. (2013) developed habitat suitability models for nesting Black-backed Woodpecker with nest location data collected following wildfire in dry conifer forests of Oregon, Washington, and Idaho (U.S.A.). Black-backed Woodpecker are disturbance specialists that favor forests burned by wildfire across much of their range (Dixon and Saab 2000). Within burned forests, nest cavities are excavated in snags located in areas of relatively high snag densities, which provide foraging opportunities for their preferred prey (i.e., bark and wood-boring beetle larvae; *Scolytidae* and *Cerambycidae*, respectively). Models were therefore developed using remotely sensed burn severity and pre-fire canopy, which indexes post-fire snag density, along with a topography variable (cosine aspect) found potentially important in previous work (Table 2.1).

Using different modeling techniques and different subsets of these data, Latif et al. (2013) developed a series of 8 models and combined their predictions using an ensemble approach. Resulting predictions described the number of models (0–8) classifying a site as suitable for nesting (hereafter "ensemble predictions"). Predictions were mainly shaped by nesting affinities for severely burned sites with moderate-to-high pre-fire canopy cover. Areas classified suitable by more models are considered more suitable, and areas classified suitable by some but not all models represent areas of uncertainty where further surveys could improve ecological knowledge and help refine models (Latif et al. 2013).

Table 2.1. Descriptions and descriptive statistics for environmental variables at nest and available sites used to develop habitat models for nesting Black-backed Woodpeckers. Descriptive statistics that equally weighted data from three surveyed wildfire locations (see Latif et al. 2013). Available sites represent survey units within which nest-searching occurred.

Variables (abbrev.)	Description	Mean, Median (95th %-iles)	
		Nest	Available

Cosine aspect (cosasp)	pixel cosine-transformed aspect derived from digital elevation model (unitless)	0.34, 0.51 (-0.98,1.00)	0.00, 0.00 (-1.00,1.00)
Burn severity (locdnbr)	median index of burn severity (change in [delta] normalized burn ratio pre- to post-wildfire) using Landsat TM satellite imagery for 0.81-ha (3×3-cell) moving window (unitless)	529.3, 515.2 (169.4,862.3)	328.1, 297.1 (-59.6,806.5)
Local canopy cover (loccc)	proportion of 0.81-ha (3×3-cell) moving window with > 40% canopy cover recorded before fire	0.85, 1.00 (0.00,1.00)	0.63, 0.89 (0.00,1.00)
Landscape canopy cover (landcc)	proportion of 314-ha (1-km radius) moving window with > 40% canopy cover recorded before fire	0.65, 0.62 (0.39,0.93)	0.59, 0.59 (0.17,0.95)

2.2 White-headed Woodpecker in unburned forests

Latif et al. (2015) developed and evaluated habitat suitability models for nesting White-headed Woodpeckers in unburned dry conifer forests of Oregon (U.S.A). White-headed Woodpeckers favor forests dominated by ponderosa pine (*Pinus ponderosa*) and characterized by forest canopy mosaics. In particular, they establish nest sites in relatively open-canopy forests but forage largely in more closed-canopy forests (Hollenbeck et al. 2011, Latif et al. 2015). To quantify these habitat associations, Latif et al. (2015) developed models using variables describing topography, canopy cover, and coverage of ponderosa-pine dominated forest compiled at a 30 m resolution at nest and available sites (Table 2.2). Latif et al. (2015) developed and evaluated two different types of models, but one developed using the Maxent modeling technique (Phillips et al. 2006) performed especially well. Maxent model predictions quantified affinities for nest sites with lower local canopy cover, higher landscape canopy cover, and a high percentage ponderosa-pine dominance.

To expedite model application particularly over large landscapes, the ArcGIS tool applies a simplified version of the published model. The simplified model excludes edge density (density of edge between high and low canopy cover patches), because it is computationally intensive to calculate and contributed negligibly to performance of the published model. Additionally, simplified model HSIs represent one version of the model fitted to all available data (published HSIs were averaged across model replicates fitted to re-sampled data subsets). In short, the simplified model generates HSIs virtually identical to the published model but reduces the time required for data processing and computation.

Table 2.2. Descriptions and descriptive statistics for environmental variables at nest and available sites used to develop habitat models for nesting White-headed Woodpeckers in unburned forests. Descriptive statistics were calculated for samples balanced across subsets of nest location data (described by Latif et al. 2015). Available sites represent areas within which nest-searching occurred.

Variables (abbrev.)	Description	Mean, Median (95th %-iles)	
		Nest	Available
Slope (slp)	pixel slope in % rise over run	3.7, 2.0 (0.0,16.3)	4.5, 3.0 (0.0,20.0)
Cosine Aspect (cosasp)[A]	pixel cosine-transformed orientation of slope (unitless)	0.05, 0.00 (-0.99,0.98)	0.00, 0.00 (-0.99,0.98)
Local canopy cover (loccc)	percent canopy cover for 0.81-ha (3×3-cell) neighborhood	40.1, 40.6 (8.7,68.4)	42.9, 42.4 (14.1,73.8)
Landscape canopy cover (landcc)	percent canopy cover for 314 ha (1-km-radius) neighborhood	43.2, 42.0 (29.9,60.1)	43.0, 42.1 (25.0,62.3)
Ponderosa pine (pipo)	Percent ponderosa-pine-dominated forest for 314 ha (1-km-radius) neighborhood	80.3, 84.0 (49.3,97.0)	73.3, 77.0 (28.0,96.9)

[A]cosasp = 0 when slp ≤ 2%

2.3 White-headed Woodpecker in burned forest of the inland Pacific Northwest

White-headed Woodpecker nest habitat relationships in recently burned forest are analogous to those in unburned forests, wherein canopy mosaics are favored for nesting (compare Wightman et al. 2010, with Hollenbeck et al. 2011, Latif et al. 2015). Wightman et al. (2010) describe a post-fire habitat model for White-headed Woodpeckers, but given subsequent work in unburned forest (Latif et al. 2015), we expected an alternate approach would be required for broad applicability. We therefore implemented the Maxent modeling technique (also used by Latif et al. 2015) informed with data from two wildfire locations in Oregon (Toolbox, 2002; Canyon Creek, 2015; Table 2.3.1) to generate a new model. We briefly summarize model structure, development, evaluation, and rationale here. Additional details will be reported in a peer-reviewed manuscript (Latif et al. In Prep).

Table 2.3.1. Summary of sampling at two wildfire locations where White-headed Woodpecker nest surveys were conducted to inform burned forest HSI model development and evaluation.

National Forest	Fire Name	Ignition Year	Years surveyed	Full extent (ha)	Surveyed extent (ha)	No. nest pixels
Fremont-Winema	Toolbox	2002	2003–2007	33,427	856[a]	46[a]
Malheur	Canyon Creek	2015	2016–2017	44,672	4347, 4727[b]	47

[a]Non-nest sites were only measured in 13 largest of 22 survey units. Area surveyed = 798 ha and 33 nests were located in these 13 units.
[b]One survey unit was replaced between years. Area surveyed was 4347 in 2016 and 4727 ha in 2017.

We expected White-headed Woodpeckers in burned forest to place nests in severely burned or otherwise open-canopy sites adjacent to more closed-canopy and unburned forest presumably used for foraging (Wightman et al. 2010). We modeled these relationships using Maxent (Phillips et al. 2006) informed by remotely sensed data describing burn severity, pre-fire canopy cover, percent coverage of ponderosa pine-dominated forest, and topographic slope (Table 2.3.2) at nest and available sites recorded at two wildfire locations, the 2002 Toolbox Fire (see Wightman et al. 2010) and the 2015 Canyon Creek Fire in Oregon.

Table 2.3.2. Remotely sensed environmental variables used to model nesting habitat for White-headed Woodpeckers in burned forest. Descriptive statistics (mean [SD]) are reported for the two

study locations where the model was developed at nest sites and available sites representing the area surveyed.

Variables (abbrev)	Description	Toolbox		Canyon Creek	
		nest	available	nest	available
Local-scale percent area burned or open (locbrnopn)	Percentage of 3×3 cell (0.81 ha) neighborhood moderately to severely burned (ΔNBR > 270) or <10% pre-fire canopy cover	95.3 (13)	81.6 (32.4)	82 (26.8)	80.4 (28.9)
Landscape-scale percent area burned or open (landbrnopn)	Percentage of 1-km radius (314 ha) neighborhood moderately to severely burned (ΔNBR > 270) or <10% pre-fire canopy cover	61.1 (19.7)	65.7 (21.5)	60.7 (14)	68.1 (13.7)
Landscape-scale percent area ponderosa pine forest (LandPIPO)[A]	Percentage of 1-km radius (314 ha) neighborhood dominated or co-dominated by ponderosa pine	74.9 (7.9)	72.3 (10.6)	59.8 (10.1)	59.2 (10.5)
Slope[a]	pixel topographic slope as % rise over run	7.3 (5.6)	7.8 (6.6)	21.3 (12.9)	23.5 (11.4)

[a]LandPIPO and Slope do not directly inform modeling but are used for *post hoc* masking of the final HSI map to restrict model application to areas with LandPIPO > 40% and Slope < 40%, representing the min and max values, respectively, observed at nest locations.

We initially developed separate models at each wildfire location and applied them across locations to test predictive performance. We measured predictive performance using AUC (area under the receiver operating curve; Fielding and Bell 1997) assessing discrimination of nest from non-nest sites, whereby AUC = 0.5 indicates discrimination no better than random, AUC = 1 indicates perfect discrimination. Models developed at Toolbox and Canyon Creek locations performed well when applied across these two locations (Table 2.3.3), so we combined data from these locations to develop a final model. Unfortunately, models did not perform well at a third location, the Barry Point Fire (Oregon, 2011; Table 2.3.3), so we recommend restricting model application to conditions characteristic of the Toolbox and Canyon Creek locations but not Barry Point (described further below in *WHWO burned forest model applicability*, MODEL

APPLICABILITY). The final model provided by the ArcGIS tool presented here describes a positive relationship with severely burned or open forest at the nest site (~1 ha) and a negative relationship with less severely burned and relatively closed forest over an area approximating a home range (314 ha; Table 2.3.2). Model HSIs designate suitable nesting habitat as areas along burned forest edges and mosaics of burned and unburned forest. Additionally, following relationships with ponderosa pine forest and topographic slope observed at individual wildfire locations (see also Hollenbeck et al. 2011, Latif et al. 2015), we restrict model application to LandPIPO and Slope values observed at nest locations (Table 2.3.2; described further below in *WHWO burned forest model applicability*, MODEL APPLICABILITY).

Table 2.3.3. Predictive performance of WHWO burned forest model(s) at individual wildfire locations. AUC ≤ 0.5 indicates discrimination of nest from non-nest sites no better than random, whereas AUC = 1 indicates perfect discrimination. Boot-strapped 95% confidence intervals (parentheses) that overlapped 0.5 were considered indicative of poor performance. Models were developed at Toolbox (TB) and Canyon Creek (CC) study locations, and applied at these plus Barry Point (BP). AUCs measuring discrimination outside where models were originally developed especially important for assessing predictive performance ([a]).

Applied at:	Developed at:		
	TB	CC	TB & CC
TB	0.76(0.68,0.85)	0.72(0.62,0.81)[a]	0.72(0.63,0.81)
CC	0.61(0.52,0.7)[a]	0.64(0.54,0.73)	0.62(0.53,0.71)
BP	0.58(0.39,0.77)[a]	0.5(0.31,0.69)[a]	0.46(0.27,0.65)[a]

2.4 Woodpeckers in Northern Sierra burned forests

We developed models for several woodpecker species to inform post-fire forest planning and habitat conservation in the northern Sierra Nevada Mountains of California. Given regional differences in forest structure, tree species composition, and woodpecker behavior (e.g., Fogg et al. 2014), we did not expect models developed in other regions to be applicable here. We therefore developed a series of models specific to this region informed by nest and non-nest location data for three target species (Black-backed Woodpecker, Hairy Woodpecker, and White-headed Woodpecker) from three wildfires that occurred in the Lassen National Forest over a 5-year period (Table 2.4.1). Nests were located by searching within *a priori* established 200-m wide belt transects following Dudley and Saab (2003).

Table 2.4.1. Summary of sampling at three wildfires in Lassen National Forest, California, for woodpecker nest locations to inform HSI model development and evaluation. Models presented here are for three woodpecker species: Black-backed Woodpecker (BBWO), Hairy Woodpecker (HAWO), and White-headed Woodpecker (WHWO).

Fire	Timing		Nesting spp.	*n*	
	Ignition	Sampling		nest	non-nest[a]
Moonlight	2007	2009–2012	BBWO	24	337
			HAWO	46	274
			WHWO	30	325
Cub	2008	2009–2012	BBWO	19	100
			HAWO	27	79
			WHWO	20	112
Chips	2012	2013–2016	BBWO	28	41
			HAWO	24	40
			WHWO	38	45

[a]non-nest sites represented a random sample drawn from within survey units for nest searching.

We briefly summarize model structure, development, evaluation, and rationale here, leaving additional details for peer-reviewed publication (Campos et al. In Prep). We initially considered metrics of topography, burn severity, and pre-fire forest structure, although only the latter two appeared in selected models (Table 2.4.2). These variables were drawn from available data sources (Mayer and Laudenslayer 1988, Rollins and Frame 2006, Miller and Thode 2007), reflected potentially informative environmental features described in the literature (Saab et al. 2009, Wightman et al. 2010, Latif et al. 2013, Tingley et al. 2014, Latif et al. 2015), and differed notably between nest and non-nest locations (Table 2.4.3). We used weighted logistic regression to relate binomial nest location data (0 = non-nest; 1 = nest) with these variables (observation weights and rationale follows Latif et al. 2016). For each species, we constructed and fitted models representing all possible combinations of environmental variables limited by sample size (max no. variables, *k* = no. nests / 10). We then selected one model for each species according to a series of criteria describing predictive performance, relative fit, model-estimated habitat suitability at nest locations, and parsimony (Table 2.4.4).

Table 2.4.2. Descriptions of environmental variables used to develop habitat models for nesting woodpeckers in burned forests of the northern Sierra Nevada Mountains. Additional variables, including descriptors of topography and tree species composition, were also considered but did not appear in selected habitat models and are therefore not listed. Local-scale variables quantified conditions at the nest site (3×3 cells; 0.81 ha), whereas landscape-scale variables quantified conditions for an area centered on the nest site approximating the size of a home range in general for many woodpecker species (1-km radius circle; 314 ha).

Variables (abbrev.)	Description
Local burn severity (LocCCmort)	median percent canopy mortality (derived from relativized delta normalized burn ratio) for 0.81-ha moving window (%)
Landscape burn severity (LandCCmort)	percent of 314-ha neighborhood with > 64% canopy mortality (derived from relativized delta normalized burn ratio) (%)
Local canopy cover (LocCC)	percent of 1-ha moving window with >40% canopy cover recorded before fire (CWHR density class M & D)
Landscape canopy cover (LandCC)	percent of 314-ha moving window with > 40% canopy cover recorded before fire
Local large-tree dominance (LocTrSize)	percent of 0.81-ha moving window dominated by DBH > 61 cm DBH trees (CWHR size class 5)

Table 2.4.3. Descriptive statistics (mean [SD]) for environmental variables used to model habitat for nesting woodpeckers in burned forests of the northern Sierra Nevada Mountains. Nesting species are Black-backed Woodpecker (BBWO), Hairy Woodpecker (HAWO), and White-headed Woodpecker (WHWO). Complete variable names and descriptions are in Table 2.4.2.

Variable	BBWO		HAWO		WHWO	
	Nest	Non-nest	Nest	Non-nest	Nest	Non-nest

LocCCmort	72.8 (37)	51.4 (43.7)	77.7 (33.7)	49.4 (43.7)	60.1 (41.2)	49.8 (43.5)
LandCCmort	33.2 (30.3)	48.2 (32)	41.3 (35.7)	46.5 (31.3)	26 (25.9)	47.9 (32.4)
LocCC	94.8 (15.6)	87 (28.7)	89.1 (28.3)	85.9 (29.7)	78.3 (37.1)	85.2 (30.5)
LandCC	79.3 (15.8)	83 (12.7)	84.5 (13.5)	81.7 (13)	79.4 (14)	81.9 (13.7)
LocTrSize	32.6 (44.2)	58.5 (43.6)	46 (45.5)	55 (44.9)	29.2 (42.3)	55.3 (44.5)

Table 2.4.4. Performance criteria used to evaluate habitat models and select from candidate models for nesting woodpecker species surveyed in the northern Sierra Nevada Mountains.

Criterion	Description	How applied
RPI[a]	Mean correlation coefficient (-1–1 range; n = 3 wildfires) relating observations with model predictions for each wildfire when withheld from model fitting via spatial cross validation	The model with highest mean RPI (n = 3 wildfires) that met all other criteria was selected.
ΔAIC_i[b]	Akaike's Information Criterion for the i^{th} model minus that of the top-ranked (lowest-AIC) model	Models $\Delta AIC_i > 6$ were excluded.
Sensitivity[c]	proportion nests classified suitable at a given wildfire using a classification threshold that maximized the sum of sensitivity (proportion nests suitable) + specificity (proportion non-nests unsuitable)	Models conferring minimum sensitivity at any one wildfire < 0.5 were excluded.
Parsimony[a]	Statistical support for model coefficients based on z-statistic	Models with statistically unsupported coefficients (p > 0.05) were excluded

[a]described by Wiens et al. (2008)
[b]described by Burnham and Anderson (2002)
[c]described by Liu et al. (2016)

The selected models described positive relationships with nest-site scale burn severity for all species, negative relationships with home-range scale burn severity by Black-backed and White-headed woodpeckers, positive relationships with pre-fire canopy cover by Black-backed and Hairy woodpeckers at various scales, and a negative relationship with large-tree dominance for Hairy Woodpecker (Table 2.4.5). Positive relationships with severely burned nest sites are consistent with patterns described for other regions (Russell et al. 2007, Latif et al. 2013, Latif et al. 2016). Scale-dependent relationships with burn severity for White-headed Woodpecker are consistent with their affinity for canopy mosaics also described elsewhere (Wightman et al. 2010, Hollenbeck et al. 2011, Latif et al. 2015). Other relationships observed here, however, may be unique to Northern Sierra forests. For example, negative relationships with home-range scale burn severity by Black-backed Woodpecker are not observed in other regions (Russell et al. 2007, Latif et al. 2013) nor in more pine-dominated portions of the Sierra Nevada Mountains (Tingley et al. 2014). Avoidance of large-tree dominated sites may also reflect a particular affinity for areas with higher densities of smaller trees in this region (Seavy et al. 2012). These region-specific relationships may enhance model predictive performance within sampled forest types of the northern Sierra Nevada Mountains but warrants some caution in applicability elsewhere (described further below under MODEL APPLICABILITY).

Table 2.4.5. Selected habitat models developed to inform habitat mapping for focal woodpecker species (Black-backed Woodpecker [BBWO], Hairy Woodpecker [HAWO], White-headed Woodpecker [WHWO]) following wildfire in the northern Sierra Nevada Mountains. All environmental covariates were *z*-scored (centered on zero and divided by SD) prior to model fitting. Performance criteria used for model selection are reported here and described in Table 2.4.4. Min sensitivity is the minimum proportion of nests classified suitable at any one of three wildfire locations using the classification threshold that maximizes sum of sensitivity and specificity (max SSS threshold).

Species	Model coefficients (mean estimates)	RPI	ΔAIC_i	Min sensitivity (max SSS threshold)
BBWO	Intercept (-0.86) + LocCCmort (1.77) + LandCCmort (-1.65) + LocCC (0.8)	0.976	2.239	0.63 (0.41)
HAWO	Intercept (-0.48) + LocCCmort (0.89) + LandCC (0.4) + LocTrSize (-0.47)	0.986	2.680	0.56 (0.51)
WHWO	Intercept (-0.56) + LocCCmort (1.5) + LandCCmort (-1.83)	0.942	0.000	0.53 (0.49)

3. MODEL APPLICABILITY

Models are restricted in applicability by the range of conditions within which they were developed. Applicability should ideally be tested with independent data before managers use model predictions to inform their decisions and planning (Heikkinen et al. 2012, Wenger and Olden 2012, Bahn and McGill 2013). Such testing is particularly critical when applying models beyond the environmental range where originally developed. In light of these principles and where models have been tested, we offer guidelines for HSI model applicability here. Additionally, we provide application masks for particular models based on these guidelines, which are described here.

3.1 BBWO Inland Pacific Northwest model applicability

Models for nesting Black-backed Woodpecker in burned forest were developed in dry conifer forests of western North America, so model applications should be restricted to these forests (Latif et al. 2013). We provide an application mask that excludes areas not characterized by dry conifer forests based on LANDFIRE-classified satellite imagery recorded in 2014. More specifically, models were developed and are therefore most applicable in recently burned and unlogged forests (≤ 5 years post-fire) of Idaho, Oregon, and Washington (U.S.A.). Models presented here are therefore not applicable in unburned forest (e.g., Bonnot et al. 2009, Fogg et al. 2014), and we expect predictive value to be lower in areas affected by salvage logging. Nevertheless, several lines of evidence suggest broad applicability in recently burned dry conifer forests: 1) ensemble predictions consistently characterized nesting distributions across the three wildfire locations representing a relatively broad geographic extent where models were developed, 2) predictions exhibited other desirable properties for prediction (for details, see Latif et al. 2013), and 3) predictive performance was high when evaluated with independent data from the Canyon Creek Fire (Oregon, 2015; Appendix B).

3.2 WHWO unburned forest model applicability

The HSI model for nesting White-headed Woodpecker in unburned forests was developed in lower elevation dry conifer forests of the East Cascade Mountains in eastern Oregon, and model applicability was verified in the Blue Mountains of western Oregon (see Maxent model in Latif et al. 2015). The model was developed in forests unaffected within 10 years by wildfire or other disturbance (e.g., insect outbreak, logging) with environmental metrics specific to green forests. Separate models quantify nesting habitat for White-headed Woodpeckers in burned forest (Wightman et al. 2010, Q. Latif and V. Saab unpublished data, Appendix A). Nevertheless, nest placement favors canopy mosaics maintained largely by mixed severity fire, so applicability should increase with increasing time since fire assuming availability of contemporarily accurate environmental data. Application of this model should also be restricted to areas with sufficient ponderosa pine-dominated forest. We observed no nest locations with < 10% coverage of ponderosa-dominated forest within a 1-km radius neighborhood, so the mask accompanying this model accordingly restricts model application. This model should be applied with caution (i.e., predictive performance should be verified with independent data) in landscapes that deviate from conditions characterizing lower elevation conifer forests of Oregon. These include the North Cascade Mountains in Washington where ponderosa pine is less dominant, forests of western Idaho characterized by more topography than Oregon forests, and southern California forests where White-headed Woodpeckers rely more heavily on large-seeded pine species other than ponderosa.

3.3 WHWO burned forest model applicability

The HSI model for White-headed Woodpecker in burned forests provided here was informed with data from two wildfire locations (Toolbox, 2002; Canyon Creek, 2015) in eastern Oregon. These wildfires burned areas consisting largely of lower elevation dry conifer forest strongly dominated by ponderosa pine (Table 2.3.1). The final model exclusively quantifies White-headed Woodpecker use of canopy mosaics (see *Woodpeckers in Northern Sierra burned forests* in CONCEPTUAL BASIS FOR HSI MODELS), a behavior generally characteristic of White-headed Woodpeckers across their range (Wightman et al. 2010, Hollenbeck et al. 2011, Latif et al. 2015).

Despite representing a general pattern, we expect some limits to model applicability. Limited representation of burned locations (n = 2) across the species range restricts information for quantifying relationships with other potentially important habitat components. Specifically, ponderosa pine and topographic slope are identified as potentially important in previous work (Hollenbeck et al. 2011, Latif et al. 2015), and relationships with these features were retained in preliminary models developed at individual locations (i.e., an affinity for ponderosa pine-dominated forest at Toolbox and avoidance of high slopes at Canyon Creek). Additionally, as for other post-fire models, model application should be restricted to dry conifer forest where we surveyed woodpecker populations. Accordingly, we offer an application mask that excludes areas with LandPIPO < 40% and Slope > 40%, and only includes dry conifer forest types based on LANDFIRE vegetation classifications.

We found poor predictive performance when applying this model at the Barry Point Fire in southern Oregon (2011; Table 2.3.3). Before fire, forests at this location were interspersed extensively with non-forest (shrubland and grassland) openings. Wildfire was probably less important for generating canopy mosaics, and because mosaics were so readily available, White-headed Woodpeckers probably did not need to actively seek openings when selecting nest sites, compromising the predictive value of our model. Additionally, coverage of ponderosa pine-dominated forest (1-km neighborhood) was relatively low (mean ≈ 30%), which may have increased its value and led White-headed Woodpeckers to focus more on ponderosa pine when selecting breeding territories and nest sites at Barry Point. We therefore caution against applying our model to areas like Barry Point characterized before fire by extensive non-forest openings and restricted coverage of ponderosa pine forest. Moreover, we suggest users compare descriptive statistics for their project areas for comparison with model-development locations. In addition to using an appropriate application mask (see above), application should be avoided in landscapes whose conditions differ substantially from those characteristics of where models were developed (see Table 2.3.2).

As with other post-fire models in this series, nest locations were collected within 5 years of wildfire, and survey units were subjected to selective-cut salvage logging. Logging was limited in extent and intensity, and varied between locations. To avoid over-fitting models to conditions at individual locations, models excluded logging variables. That models nevertheless showed predictive ability between Toolbox and Canyon Creek locations suggests logging was not extensive enough to negate model applicability. Nevertheless, too much logging would likely compromise accuracy of remotely sensed data upon which models depend. We expect this model (and others in this series) will be most useful for informing management planning prior to any implementation of salvage logging.

3.4 Applicability of Northern Sierra models

HSI models for woodpeckers in the northern Sierra Nevada Mountains were developed and are applicable in burned forests of this region. Models were primarily developed in Sierra Mixed Conifer, White Fir, and Red Fir forest types (designated by California Wildlife Habitat Relationship System [CWHR]; Mayer and Laudenslayer 1988). Accordingly, we offer a mask that restricts application of Northern Sierra models to areas within 1 km of relatively large forest patches (min = 314 ha) of these types.

Models were developed and evaluated with data collected within 5 years following three wildfires that occurred in ~80 km wide area (~10-20 km spacing between fire perimeters; Table 2.4.1). Sampled landscapes were affected to some extent by selective harvest salvage logging. Nevertheless, sampling avoided extensively logged areas and models did not quantify relationships with logging to avoid over-fitting to conditions at surveyed fires. Thus, we intend models for application immediately after wildfire and before salvage logging to inform post-fire management planning. Models may also be applied in areas affected by limited salvage logging (i.e., $\lesssim$20% of the landscape treated with selective harvest[1]), whereas predictive performance would likely decline in more extensively treated areas. Some environmental relationships quantified by these models differed from those observed in forests of other regions dominated more so by pine (e.g., a negative relationship with home range scale burn severity for Black-backed Woodpecker; contra Tingley et al. 2014). Therefore, we expect poorer applicability in

[1] Tractor- or helicopter-based salvage treatments occurred on the Lassen and Plumas National Forests. Prescriptions on both forests retained an average of 4 of the largest snags along with some non-merchantable trees (<12 in DBH) per acre. In some areas of the Plumas National Forest, the prescription retained 13% of each unit in untreated leave islands where all snags were left standing, with few merchantable trees left in the remaining matrix.

pine-dominated forests in drier regions of the Sierra Nevada Mountains, and in other mountain ranges outside California.

4. INSTRUCTIONS FOR TOOL IMPLEMENTATION

Application tools described in this manual are operated within an ArcGIS environment. Users must have access to ArcGIS 10, a basic understanding of how to operate this software, and spatial data layers for clearly defined study areas. Steps provided here detail how to retrieve and compile environmental data into GIS layers required as model inputs, and how to access and implement model application tools.

Currently, most tools are ideally operated within the Forest Service Citrix environment or another environment with access to the T drive (except Northern Sierra woodpecker tools). In particular, the optimal workflow for operating these tools relies on input generation tools to facilitate preliminary data processing, and some input generation tools require access to baseline data stored on the T drive. Users with access to the T drive can operate tools located at "T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX". Alternatively, users can download and extract the entire folder structure needed to operate the tool at "…HSI_applic_tool\FIRE-BIRD_v0.1.zip" or from the Region 6 website under the heading "FIRE-BIRD: Habitat Model Application Tools for Disturbance-associated Woodpeckers". Hereafter, the location "TOOLBOX" refers to either the folder on the T drive or the folder extracted from the FIRE-BIRD_v0.1.zip file to a personal workstation. For users without access to Citrix or the T drive, some input generation tools will be unavailable, in which case users will need to follow alternate instructions for manual input generation (see operating instructions below).

Once the user has verified access to the toolbox on Citrix or extracted the toolset to an alternate location, they can follow steps provided below for their tool of interest. Throughout these instructions, we suggest names for the various files in particular steps. These tools allow users to drag and drop input files required for operation, so users are not required to follow our suggested naming convention, but we nevertheless suggest doing so to ease following our instructions.

The primary output provided by these tools are raster layers mapping the relative likelihood for species occurrence, i.e., habitat suitability indices (HSIs). Subsequent to these instructions, we provide additional guidelines for interpretation of HSIs to inform forest planning (see **5. GUIDELINES FOR HSI MAP INTERPRETATION**).

4.1 BBWO instructions for the Inland Pacific Northwest

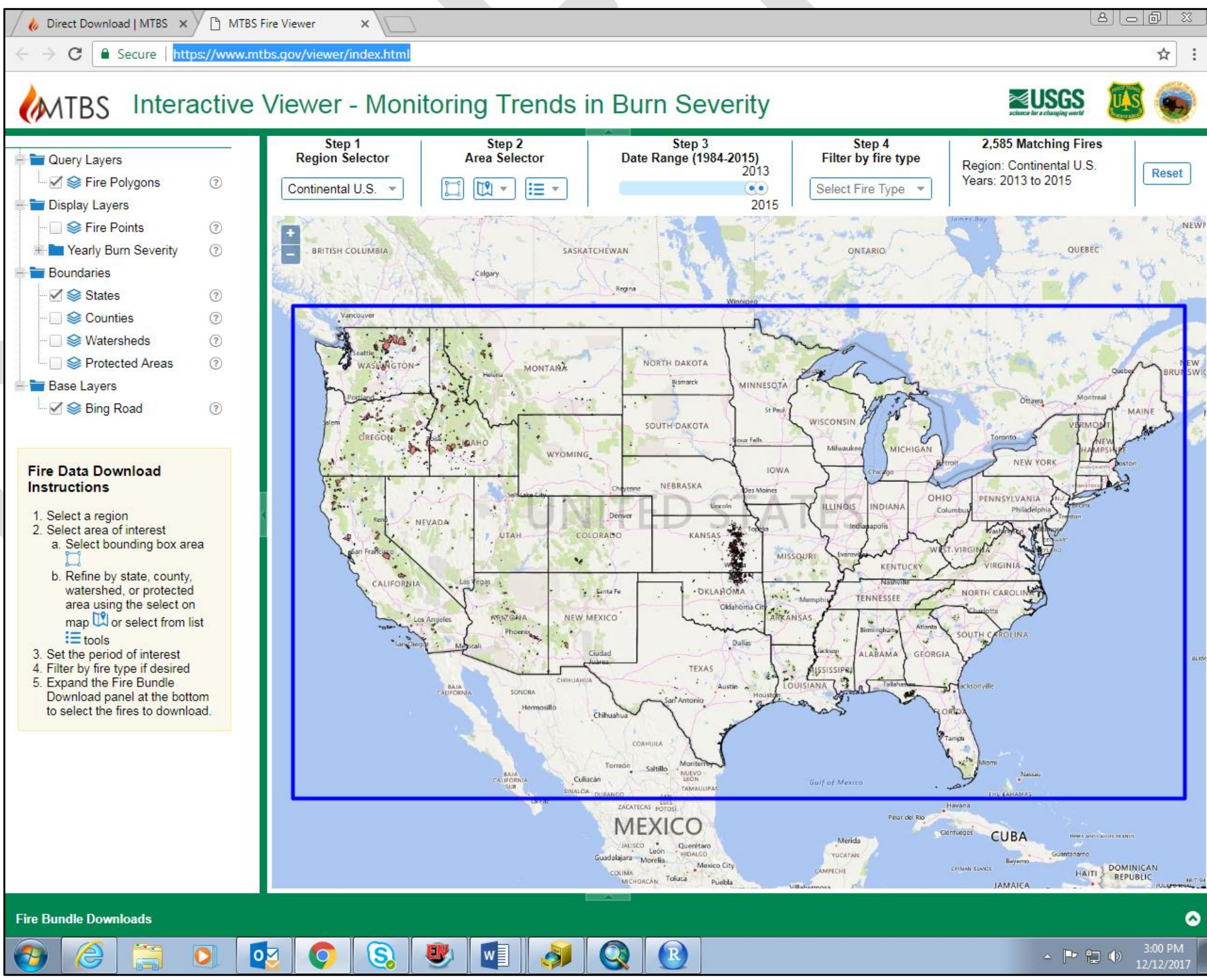
The principal output generated by the application tool for nesting Black-backed Woodpeckers in the Inland Pacific Northwest and northern Rocky Mountains describes a composite of predictions from multiple models, i.e., ensemble model predictions. Additionally, the tool allows optional generation of habitat maps from individual models that make up the ensemble. The study area must have been burned by relatively large wildfires (1000 acres in western U.S.) for the necessary data to be retrievable (Saab et al. 2007, Latif et al. 2013). The user can choose among various file extensions indicating format for output layers, of which we recommend ".tif" or ".img" formats for flexibility in file naming.

I. Retrieve and compile environmental data layers. In this step you will retrieve and process remotely sensed data to compile the variables listed in Table 2.1. **Pathnames for data files**

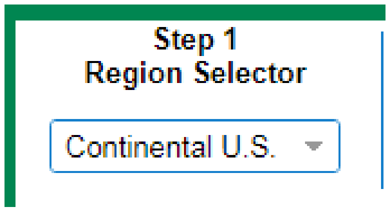
cannot have spaces, so when saving the data layers, ensure that no parent folders in the file path names have spaces. For example, “C:\GIS\Data\Black-backed Woodpecker\dnbr.tif” is an invalid path name; the folder named “Black-backed Woodpecker” needs to renamed to “Black-backedWoodpecker” or “BBWO”.

A. Retrieve burn severity data:

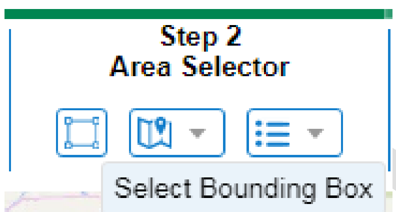
1. Go to the Monitoring Trends in Burn Severity interactive viewer for querying and downloading remotely sensed wildfire data: https://www.mtbs.gov/viewer/index.html.



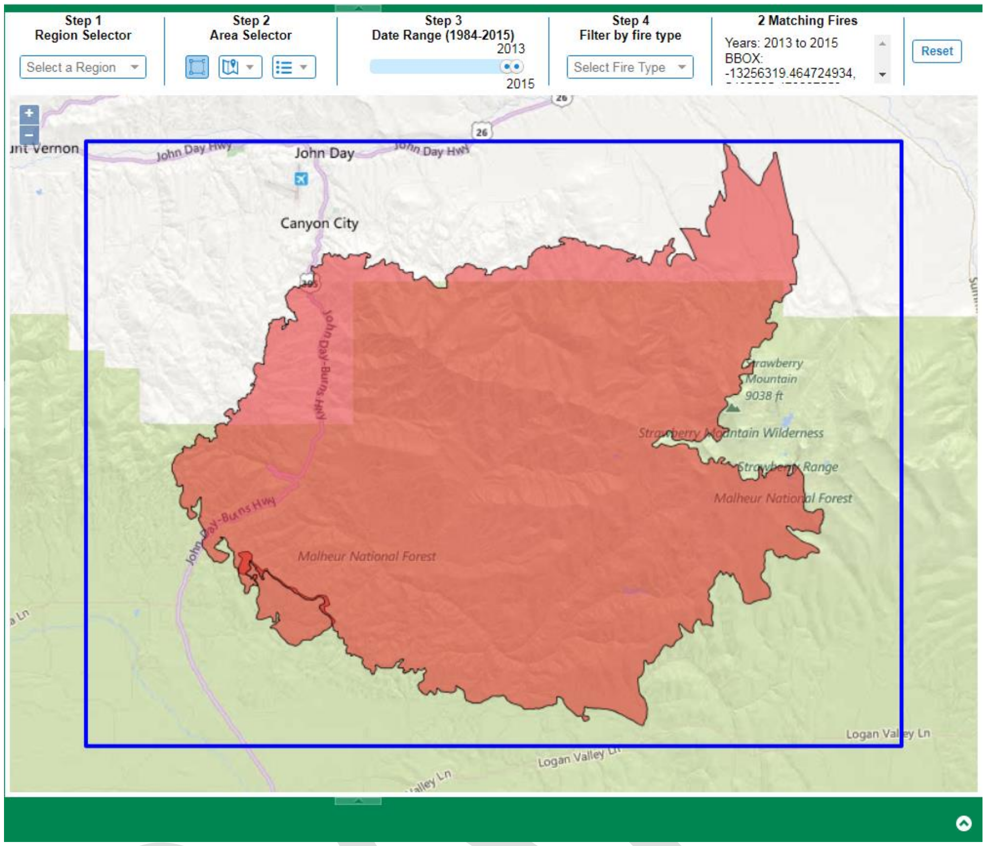
2. Follow Steps at the top of the viewer to locate your wildfire location. The example here shows retrieval of data for the 2015 Canyon Creek Fire in Oregon.
    a. Select "Continental U.S." in the drop down menu under Step 1.



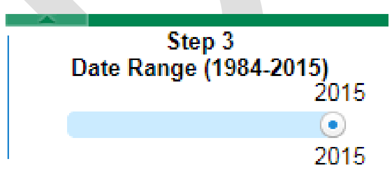
    b. When you hover your cursor over the first of three buttons under Step 2, the label "Select Bounding Box" will appear. Click on this button.



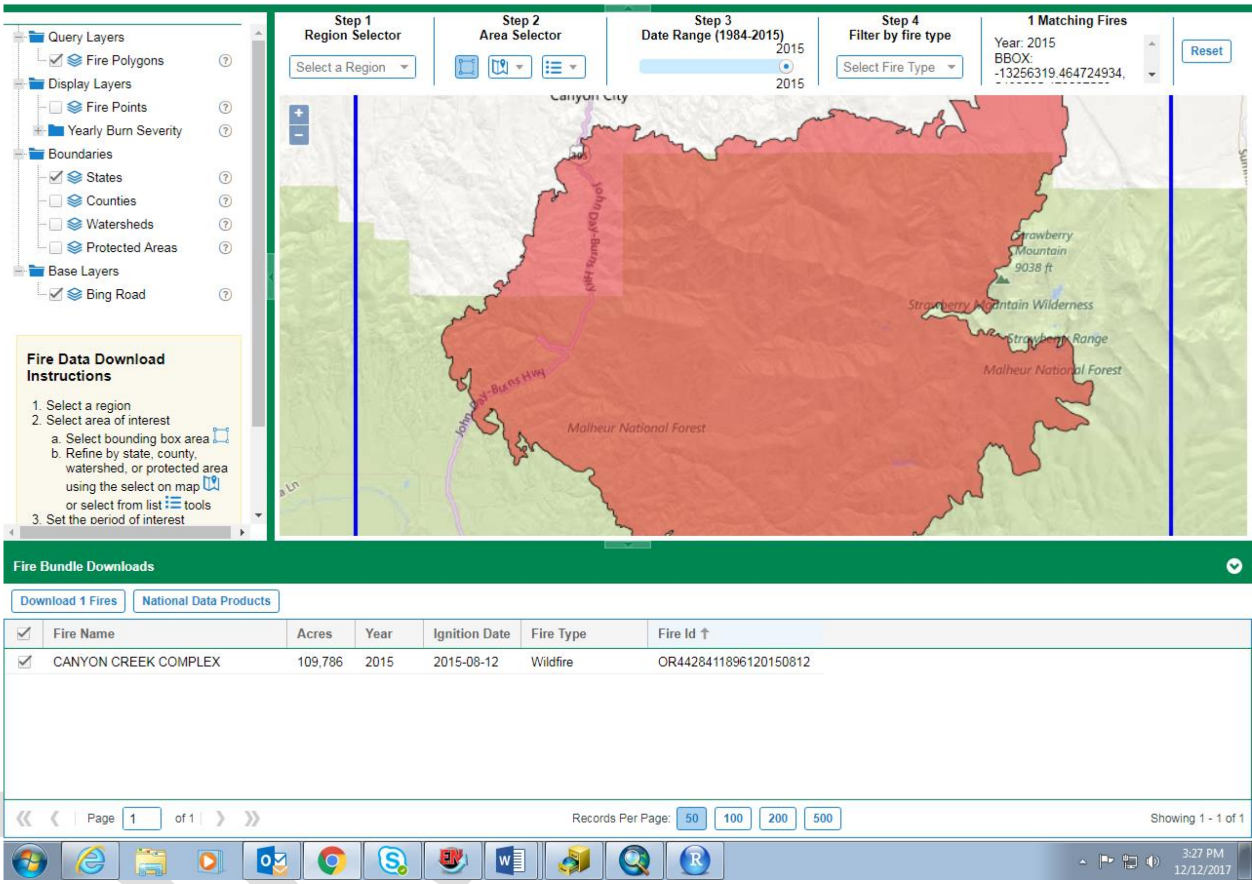
    c. In the map, drag a box over the geographic region in which the wildfire location of interest is located. You may do this multiple times until you have zoomed in to only the area containing the target wildfire location.

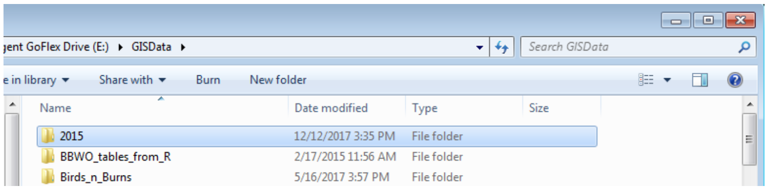


d. Under Step 3, adjust the scroll bar to include the ignition year for the wildfire of interest. The scroll bar can include multiple years, in which case multiple wildfire locations may appear in the map viewer. There will be a chance to select from among multiple locations later, but to subsequent steps easier, adjust the scroll bar to only include the ignition year for your wildfire of interest.



e. At this point, there should only be one or a few wildfire locations displayed in the map filter. If there are >1, you can set the “fire type” filter under Step 4 to “Wildfire” to further reduce the size of the query. Otherwise, click on the arrow at the bottom right to open up the “Fire Bundle Downloads” window. If multiple locations are displayed, toggle the check boxes on the left until only desired locations are check marked. Then click on the “Download Fires” button on the top left of the “Fire Bundle Downloads” window.

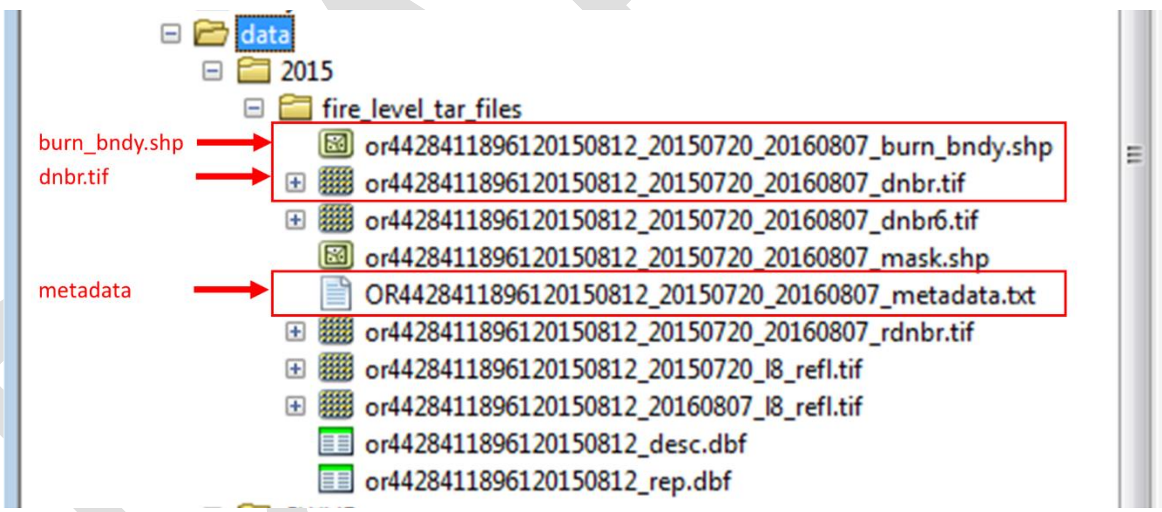


3. Move the downloaded zip file to an appropriate location and unzip it with Winzip, 7zip, or other file compression software. Right-click on the compressed file to find extraction options. The extracted folder will be named according to the ignition year of your wildfire location. 

4. Within this folder, navigate into the folder named “fire_level_tar_files” to find the “…tar.gz” file corresponding with your wildfire location. The file name will begin

with the two-letter state code in which the fire was located followed by a long series of numbers and finally the ".tar.gz" extension. Extract this file using available software as outlined in the previous step (I.A.3).

5. The extracted file will have the same name but only an extension of "…tar". Again, extract this file using steps outlined for the previous two steps (I.A.3–4).
6. Review extracted files. In ArcCatalog, navigate to the folder containing the extracted files. In general, the fire perimeter polygon shapefile will end in "…burn_bndy.shp" and the burn severity raster will end in "…dnbr.tif" (hereafter "burn_bndy.shp" and "dnbr.tif", respectively). Open the metadata.txt file and look under "Products List:" for explanation of the various other extracted files.



Note on RAVG data: For assessment of recent fires where MTBS data are unavailable, RAVG data can be used instead. We compare HSIs and their predictive performance when produced with MTBS versus RAVG data in Appendix A (Section 9.1). RAVG data can be obtained using the online query

tool at https://www.fs.fed.us/postfirevegcondition/index.shtml. See I.A under 4.4 *Northern Sierra instructions* for retrieving RAVG data.

B. Compile the 4 input variables needed to apply the published HSI (ensemble) model (Latif et al. 2013) using the associated input generation tool described here. **Note: This input generation tool can only be operated within Forest Service Citrix environment or from an environment with access to the Forest Service T drive. If neither of these conditions are met, follow step I.C to compile inputs from alternate data sources.** This tool only requires burn_bndy.shp and dnbr.tif files from the user (retrieved in steps I.A). The tool develops required input layers (Table 2.1) with these files and default topography and canopy cover data accessed automatically from the T drive. The default canopy cover layer provides 2012 gradient nearest neighbor (GNN) data from LEMMA (Landscape Ecology, Modeling, Mapping, and Analysis; *ref*) where available (Oregon, Washington) and data from LANDFIRE (*ref*) where GNN data were not available (Idaho, Montana). These data may represent pre-fire canopy cover for wildfires that burned in 2012 or later unless additional disturbance occurred between recording default imagery (after 2011 but before 2012 fire seasons) and the wildfire of interest. We have observed default imagery poorly representing pre-fire canopy cover at some locations for reasons unknown, so users should carefully inspect default canopy cover data to verify they make sense and are reasonably accurate. In cases where default canopy cover data are deemed sufficient, proceed with steps I.B.1–6 to compile input layers. **For wildfires that occurred before 2012 or for which default imagery are unlikely to accurately represent canopy coverage immediately preceding wildfire (e.g., due to additional**

disturbance in the interceding period), additional steps will be required to compile canopy cover inputs from an alternate source. If alternately sourced canopy cover inputs are needed, follow steps I.B.1–6, but then delete resulting loccc and landcc layers and then follow steps I.C.4–6 (i.e., skip I.C.1–3) to generate replacement inputs.

1. From ArcCatalog, navigate to the "TOOLBOX → Habitat Suitability Modeling.tbx → Input Development" and open the "Generate Inputs Black-backed Woodpecker Model" tool. As stated above, this folder is located at "T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX". The user must either access this location when running ArcCatalog on Citrix or download this entire folder onto his/her local machine.
2. Identify or create a folder where you want model inputs to be stored. Under "Workspace", navigate to this folder. Then click "Add".
3. For "Fire Perimeter", navigate to the burn_bndy.shp file downloaded from MTBS (steps I.A). You can either navigate from outside the tool interface and drag and drop this file into the "Fire Perimeter" box, or navigate from within the tool and click "Add".
4. For "dNBR", use the dnbr.tif file downloaded from MTBS (steps I.A). Again, either navigate from outside the tool interface and drag and drop dnbr.tif, or navigate from the "dNBR" box and click "Add".
5. Click OK (All outputs will be stored in the INPUTS folder in your designated workspace).
6. Close this dialog when completed successfully.

C. *Optional* – Steps for compiling input layers (locdnbr, loccc, landcc, and cosasp) from alternate data sources are provided here. **These steps should be followed in cases where the user lacks access to the Forest Service T drive, or if default canopy cover layers are insufficient.** These steps assume the user has obtained four layers for their project area: 1) dnbr.tif and burn_bndy.shp files retrieved in I.A, 2) a 30m-pixel elevation raster layer (e.g., a digital elevation model layer from LANDFIRE), and 3) a 30m-pixel raster layer that either provides continuous canopy cover (%) or discriminates high (>40%) from low (≤40%). Raster layers (dnbr.tif, elevation, and canopy cover) should cover all areas inside the burn_bndy.shp file and extend ≥ 1 km beyond (see Step I.A.3). If this criterion is not met, layers should at least cover all areas within and ≥ 1 km outside study units relevant to management planning or decisions, in which case the user should use a shapefile describing study unit boundaries in place of burn_bndy.shp in step I.C.2 below. For users with access to the T drive but requiring alternately sourced canopy cover data, follow steps I.B.1–5 above, but then delete resulting loccc and landcc layers and then follow steps I.C.4–6 (i.e., skip I.C.1–3) to generate replacement inputs. Note: We suggest following file naming directions to keep track of different files referenced in these instructions.

1. Identify or create a folder where you want model inputs to be stored. Place intermediate and final layers generated from steps I.C.2–4 below in this folder. The remainder of these steps will refer to this folder as your “workspace”.
2. Apply the “Focal Statistics” tool to dnbr.tif (downloaded in I.A.3) to generate the locdnbr input layer.

a. Open the tool from ArcCatalog (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).

b. Designate dnbr.tif as the "Input Raster".

c. Apply the default neighborhood of 3×3 cells with "Statistics type" set to "Median". Name the resulting layer "lcdnbrpre".

d. Clip lcdnbrpre to the fire perimeter to produce final locdnbr input layer. Open TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask. Designate lcdnbrpre as the Input layer and burn_bndy.shp as the mask. Designate the workspace as the output location and name the output file "locdnbr".

3. Generate cosine aspect input layer (cosasp) from raw elevation.

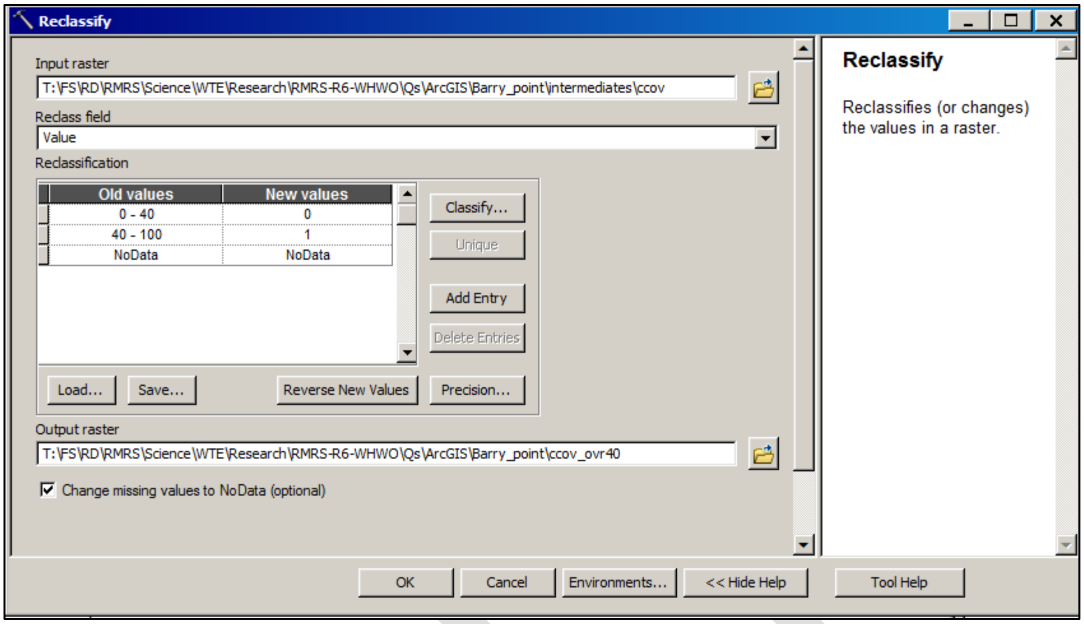
   a. Prior to following these instructions, locate a raster layer that describes elevation at 30m resolution (e.g., digital elevation model layer from LANDFIRE).

   b. Apply the "Aspect" tool to this layer (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Aspect).

   c. The resulting raster layer will be in degrees. One can calculate cosine aspect using the raster calculator tool included with ArcGIS software, but doing so requires conversion of aspect from degrees to radians. To make this step simpler, we recommend using the "Cosine (degrees)" tool that we have included in the "T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX\Habitat Suitability Modeling.tbx\Input Development" folder (or where you copied this folder on your desktop at the beginning of these instructions). Double click on the

"Cosine (degrees)" tool, drag and drop the aspect raster generated in the previous step as the input for this tool, and name the resulting tool "casppre".

4. Begin with a raw canopy cover layer that either describes a continuous percentage or discriminates between low (<40%) and high (>40%) canopy cover at a 30m resolution. The available sources for retrieving such data will depend upon wildfire timing and geographic region of the user's study location (e.g., GNN, LANDFIRE, VMAP). Once such a layer is obtained, carry out the following steps to compile loccc and landcc layers. If the raw canopy cover layer is categorical and discriminates high (>40%) with raster value = 1 from low (≤40%) with raster value = 0, name this file "ccov_ovr40" and skip to Step I.C.4. If the raw layer does not match this structure exactly but contains sufficient information to discriminate high (>40%) from low (≤40%) canopy cover, name it "ccov" and follow steps I.C.3.a–c which direct use of the "Reclassify" tool to classify high (>40%) versus low (<40%) canopy cover. **If the raw canopy cover layer is not continuous and does not include the 40% cutoff for defining categories, the user will need to seek an alternate data source (e.g., a forest- or region-specific data repository)**.
    a. In ArcToolbox, open "TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Reclassify".
    b. Designate "ccov" as the "Input raster". Adjust the "Reclassification" table to match the image below. If the raw layer is continuous, the user's table will look like the one depicted below. Otherwise, manipulate the table however necessary to generate two classes: value = 0 for <40% and value = 1 for >40%.

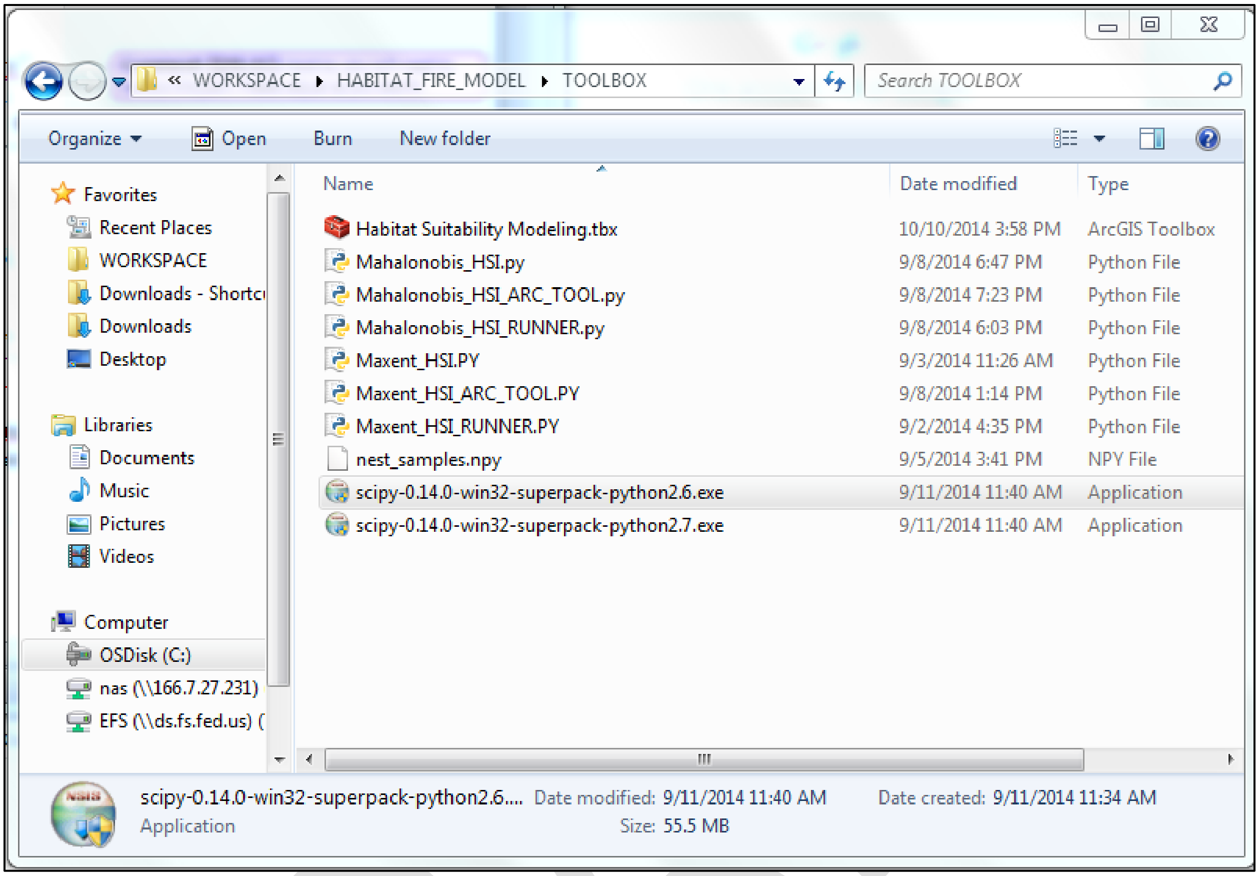


   c. Select an appropriate location and name this file "ccov_ovr40".

5. Apply the "Focal Statistics" tool to the "ccov_ovr40" layer to generate local- and landscape-scale canopy cover layers.
   a. Open the tool from ArcCatalog (Spatial Analyst Tools → Neighborhood → Focal Statistics).
   b. Designate ccov_ovr40 as the "Input Raster".
   c. Apply the default neighborhood of 3×3 cells with "Statistics type" set to "Mean". Name the resulting layer "lccpre".
   d. Apply a 1-km radius neighborhood (select the "Circle" option under "Neighborhood", select the "Map" option for "Units", and use 1000 for the "Radius"), set "Statistics type" to "Mean", and name the resulting layer "ldcpre".
   e. Verify that lccpre and ldcpre are proportions (range: 0–1) and not percentages (range: 0–100). Right click on each layer, click "Properties" at the bottom of the drop-down menu, and scroll to the bottom. Inspect min and max values to verify each layer is a proportion.

6. Clip lccpre, ldcpre, and casppre using locdnbr (generated in Step I.3) as a mask and snapping layer to generate the final loccc, landcc, and cosasp layers.
    a. Open the "Extract by Mask" tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask).
    b. Designate the "loccpre" layer as the Input Raster and locdnbr as the mask data. Open the "Environments" window.
    c. Under "Output coordinates", import the coordinate system from locdnbr.
    d. Under "Processing Extent", set locdnbr as the "Snap Raster".
    e. Click OK.
    f. For "Output raster", navigate to the location containing locdnbr and cosasp layers (i.e., INPUT folder generated in I.3) and name the output layer "loccc".
    g. Repeat steps above (I.C.4.a–f) for ldcpre and casppre to generate landcc and cosasp input layers, respectively.

II. Install scipy module (Note: if running the tool on Citrix, you can skip to step III) – Before running the GIS model application tool, install the "scipy" Python module upon which the tool relies. Open the "TOOLBOX" folder from Windows Explorer. We have provided two executable files in this folder for installing the "scipy" module. The correct file to run will depend upon which version of Python is installed on your computer. If you have ArcGIS 10.1 or newer, double click on the **`scipy-0.14.0-win32-superpack-python2.7.exe`**. If you have ArcGIS 10.0 double click on the **`scipy-0.14.0-win32-superpack-python2.6.exe`**.



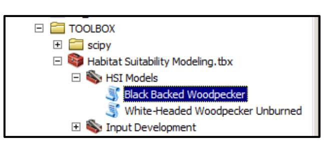
Follow the install prompts. Ensure that the directory where you install the scipy package to corresponds to the ArcGIS install locations:

A. For ArcGIS10.0 – C:\Python26\ArcGIS10.0\Lib\site-packages

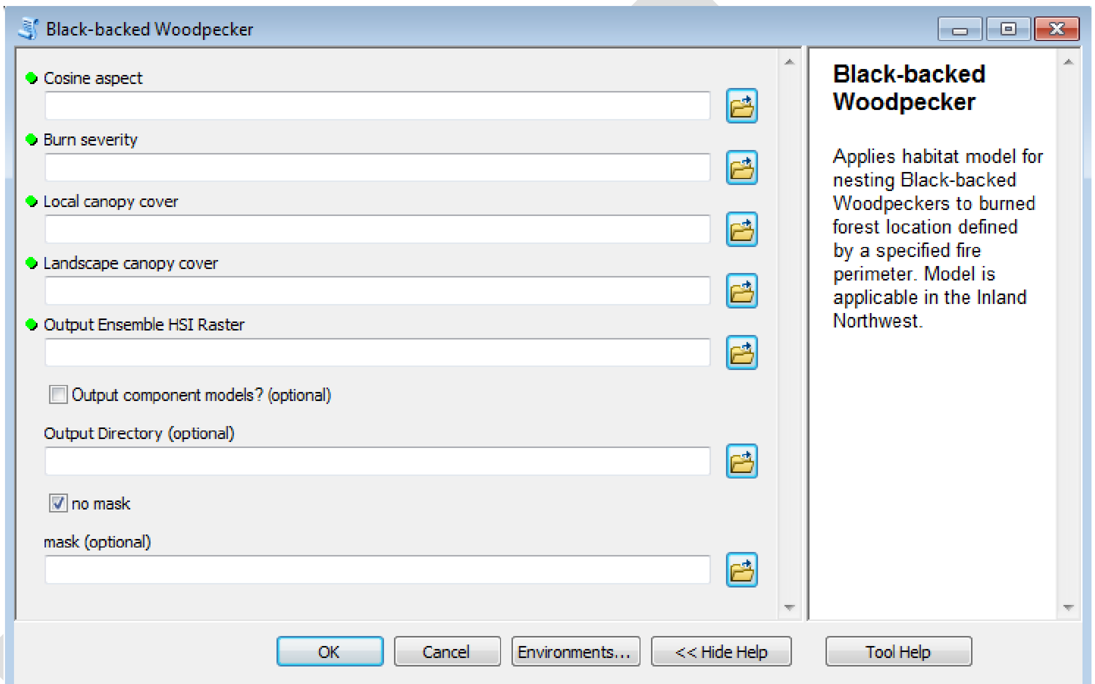
B. For ArcGIS10.1 – C:\Python26\ArcGIS10.1\Lib\site-packages

III. Run model application tool

A. From ArcCatalog, navigate to "TOOLBOX →Habitat Suitability Modeling.tbx", open the "HSI models" toolbox, and then open the "Black Backed Woodpecker" tool.



B. For “Cosine Aspect”, “dNBR”, “Local canopy cover”, and “Landscape canopy cover” inputs, use cosasp, locdnbr, loccc, and landcc input rasters, respectively, located in the INPUTS folder in your workspace (see Steps I.B/I.C). Either navigate to the INPUTS folder from outside the “Black-backed Woodpecker” tool dialog box and drag and drop each input layer, or navigate from within the dialog box and click “Add” to designate each layer.



C. Designate an appropriate location and filename for the Output Ensemble HSI raster. Click the button with the folder icon to the right, locate your workspace, and create a meaningful name, e.g., “BBWO_ensemble_HSI.tif”. Again, alternate file formats available for rasters can be specified, but we recommend “.img” or “.tif” because these allow longer filenames than the default ArcGrid format (no extension).

D. Select masking option. The user must have either the “no mask” box checked or provide a raster layer to serve as a mask for the final HSI output layer. If neither is true, the tool will throw an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask at TOOLBOX → masks → BBWO → dcfmask. This mask includes all areas characterized as dry conifer forest, which we identified as 20 LANDFIRE vegetation types (listed in metadata) based on 2014 imagery. Alternatively, the user may provide a comparable mask that covers their project area or check the “no mask” box, bearing in mind limitations to model applicability described above (see *BBWO Inland Pacific Northwest model applicability*, MODEL APPLICABILITY).

E. If individual HSI model outputs (i.e., the components of the ensemble output) are desired, check the “Output component models?” box and designate a folder where you want these outputs stored. A folder named “OUTPUTS” will be automatically generated within the designated folder, and individual HSI model layers will be stored in the “OUTPUTS” folder. Click on OK, the model will run. A series of progress bars will flash. If necessary, close the results window once “succeeded” is displayed. To view the ensemble model output, navigate to the file named in step III.C (“BBWO_ensemble_HSI.tif”), and then select preview pane. Select “Geography” in the dropdown menu at the bottom of the preview pane to preview the HSI map, or “Table” to view pixel counts for each suitability level (0–8; i.e. the number of models predicting each pixel as suitable).

4.2 WHWO instructions for unburned forests

The output generated by this tool is a 30m resolution raster layer with HSI values ranging from 0 to 1 (i.e., least to most suitable). We have posted habitat maps generated by this model for forest conditions recorded in Oregon (where the model was developed and evaluated) during 2002 and 2012 (T:\FS\RD\RMRS\Science\WTE\Research\RMRS-WHWO\Oregon_hsi_maps\WHWO_OR_HSI_maps.gdb). We intend the application tool for landscapes not reflected by default maps. Such landscapes would include:

1. Landscapes requiring adjustment for disturbance between recording of default imagery and the time period of interest.
2. Landscapes just outside Oregon state boundaries but still within conditions similar to where the model was developed (e.g., southern Washington, western Idaho, and northern California). Users applying the model outside of Oregon should be aware of the increasing need to evaluate the model with independent data from the targeted project area as one moves farther from Oregon.
3. Projected landscapes representing future or historic conditions under alternate climate or management scenarios.

Under these situations, users would have to obtain relevant spatial data describing continuous percent canopy cover and the distribution of forests dominated by ponderosa pine (*Pinus ponderosa*).

There are two disclaimers for users to acknowledge prior to following instructions for this tool. First, additional data processing steps will be required if users are not operating ArcGIS within the Forest Service Citrix environment and if users do not have access to the Forest Service T drive (also true for Black-backed Woodpecker tool). We provide additional "optional" data processing instructions for these users as we did for Black-backed Woodpecker in burned forest.

Second, Python imposes memory limitations on the implementation of ArcGIS tools. Unlike burned forest projects, unburned forest project areas could conceivably be large enough for memory to be limiting. In such cases, users will need to break up their project area into subunits, implement the tool following our instructions for each subunit, and then stitch resulting subunit output layers together using one of two raster mosaic tools (ArcToolbox → Data Management Tools → Raster → Raster Dataset → Mosaic, or Mosaic to New Raster in same location). We have successfully implemented the tool for study areas whose input layers consist of ~16 million pixels (1.4×10^6 ha) but failed with study areas consisting of ~30 million pixels (2.7×10^6 ha). Thus, for large project areas, we suggest aiming for subunits no larger than 16 million pixels in extent. For irregularly shaped project areas, users should be aware that memory is limited by the entire extent of input layers not just the area for which environmental values are compiled (i.e., including NoData pixels). Thus, users should check the total number of pixels contained in input raster layers (right click on layer and see Properties) prior to implementing this tool or if an error is reported when implementation is attempted.

I. Retrieve and compile data layers. In this step you will process remotely sensed data to compile the variables listed in Table 2.2. Pathnames for data files cannot have spaces, so when saving the data layers, ensure that no parent folders in the file path names have spaces. For example, "C:\GIS\Data\White-headed Woodpecker\cancov.tif" is an invalid path name; the folder named "White-headed Woodpecker" needs to renamed to "White-headedWoodpecker" or "WHWO".

A. Project_area shapefile – Obtain or create a polygon shapefile that delineates the entire area within which habitat suitability needs to be mapped. Label this shapefile “Project_area.shp”.

B. Canopy cover layer – Obtain or generate a raster layer that quantifies continuous canopy cover (%) at a 30m pixel resolution for the landscape of interest. This layer needs to cover all areas inside the Project_area.shp boundaries and extend ≥ 1 km outside this area. Name this layer “cancov”.

C. Ponderosa pine layer – Obtain or generate a 30m resolution raster layer that indicates whether or not each pixel is classified as forest dominated or co-dominated by ponderosa pine (PIPO). This layer should be valued so that 0 = non-PIPO and 1 = PIPO dominant or co-dominant forest. Additionally, this layer needs to cover all areas inside the Project_area.shp polygon and within 1 km outside the Project_area.shp polygon boundaries. Name this layer “pipo_class”.

D. If operating in the Citrix environment or a local environment with access to the Forest Service T drive, run input generation tool. **If the T drive is inaccessible, skip to step E for guidelines on generating inputs without the input generation tool.**

   1. From ArcCatalog, navigate to the “TOOLBOX → Habitat Suitability Modeling.tbx → Input Development” and open the “Generate Inputs White-headed Woodpecker Unburned Model” tool.
   2. Under “Workspace”, navigate to a folder where you want model inputs to be stored.
   3. Under “Project Area Boundary”, navigate to the Project_Area.shp file.
   4. For “Percent canopy cover”, use the cancov layer (I.B), and for “Ponderosa pine”, use the pipo_class layer (I.C).

5. Click OK (All outputs will be stored in the INPUTS folder in your designated workspace).

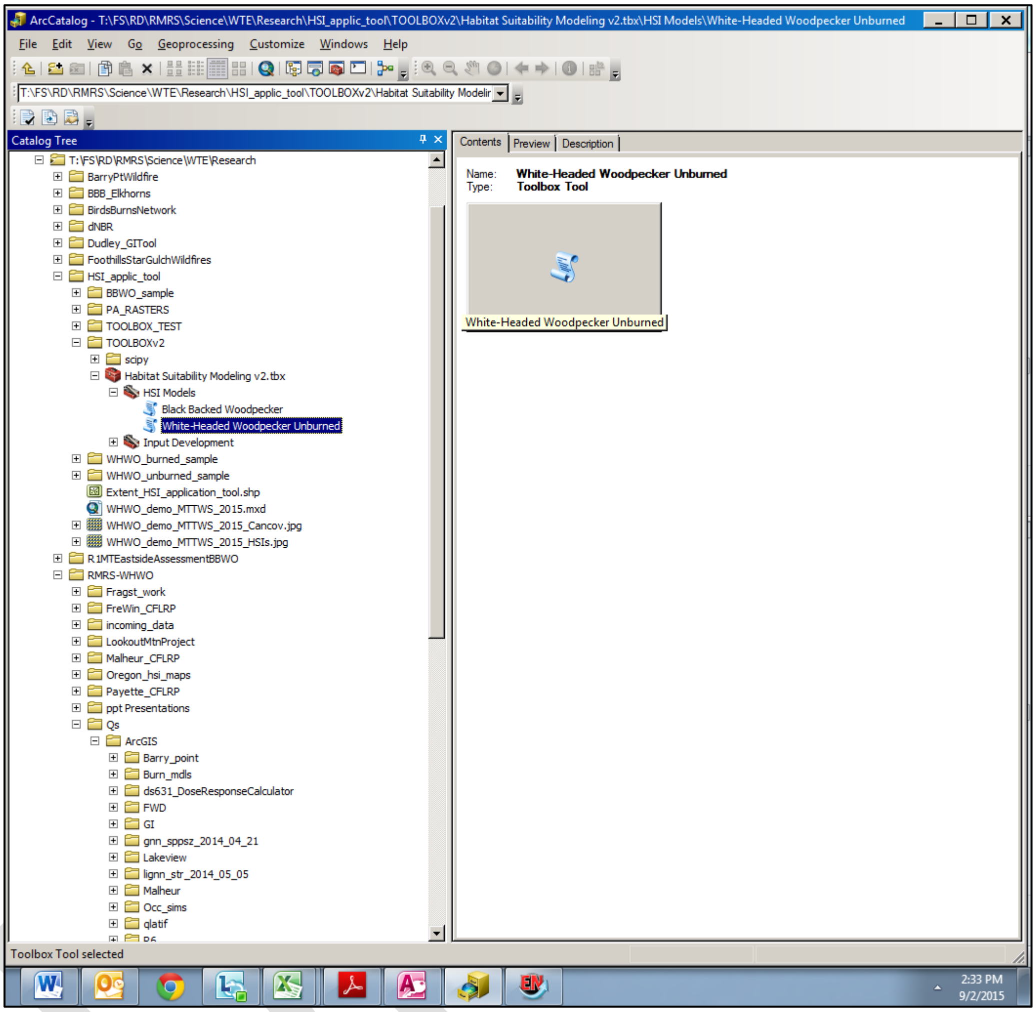
E. *Optional* – Guidelines for generating inputs for WHWO model application tool for unburned forest without the input generation tool (i.e., when the T drive is inaccessible).

1. Apply the “Focal Statistics” tool to the “cancov” layer to generate local- and landscape-scale canopy cover layers.
    a. Open the tool from ArcCatalog (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).
    b. Designate cancov (see Step I.B above) as the “Input Raster”.
    c. Apply the default neighborhood of 3×3 cells with “Statistics type” set to “Mean”. Name the resulting layer “lccpre”.
    d. Repeat I.E.1a–1c, and apply a 1-km radius neighborhood (select the “Circle” option under “Neighborhood”, select the “Map” option for “Units”, and use 1000 for the “Radius”), set “Statistics type” to “Mean”, and name the resulting layer “ldcpre”.
2. Apply the “Focal Statistics” tool to the “pipo_class” layer to generate a layer describing the percent coverage of ponderosa pine-dominated forest.
    a. Open the tool from ArcCatalog (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).
    b. Designate “pipo_class” (see Step I.B above) as the “Input Raster”.
    c. Apply a 1-km radius neighborhood (select the “Circle” option under “Neighborhood”, select the “Map” option for “Units”, and use 1000 for the “Radius”), set “Statistics type” to “Mean”, and name the resulting layer “pipopre”.

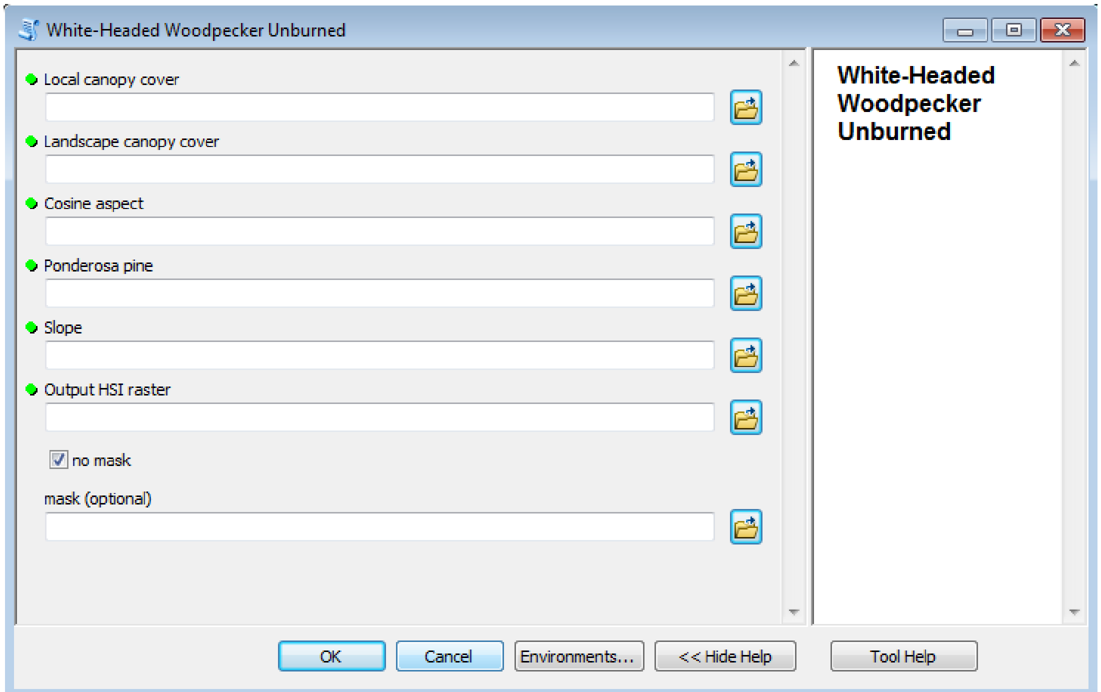
3. Clip lccpre, ldcpre, and pipopre using the “Project_Area.shp” polygon layer (created by user in Step I.A).
    a. Open the “Extract by Mask” tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask). Designate the “lccpre” as the “Input Raster” and the “Project_Area.shp” file as the mask.
    b. Open the Environments Window within this tool. Under “Output coordinates”, import the coordinate system from “Project_Area.shp”. Under Processing Extent”, set “cancov” as the “Snap Raster”. Note: it does not matter which coordinate system or snap raster is used, as long as the same ones are used for all input layers.
    c. Designate an appropriate location for all input layers (e.g., an INPUT folder in your workspace), name the output layer “loccc”, and click “OK”.
    d. Repeat steps I.E.3a–3c for “ldcpre” and “pipopre” and name respective output files “landcc” and “pipo”.

II. Run model application tool

A. From ArcCatalog, navigate to "TOOLBOX → Habitat Suitability Modeling.tbx → HSI Models" and open the "White-headed Woodpecker Unburned" tool.



B. For "Local canopy cover", "Landscape canopy cover", "Cosine aspect", "Ponderosa pine", and "Slope", use loccc, landcc, cosasp, pipo, and slp input rasters, respectively, located in the INPUTS folder in your workspace (see Steps I.D/I.E). Either navigate to the INPUTS folder from outside the tool dialog box and drag and drop each input layer, or navigate from within the dialog box and click "Add" to designate each layer.



C. For "Output HSI raster", designate an appropriate location and filename for the output raster. Click the button with the folder icon to the right, locate your workspace, and create a meaningful name, e.g., "WHWO_unburned_HSI.tif". Again, alternate file formats available for rasters can be specified, but we recommend ".img" or ".tif" because these allow longer filenames than the default ArcGrid format (no extension).

D. Select masking option. The user must have either the "no mask" box checked or provide a raster layer to serve as a mask for the final HSI output layer. If neither is true, the tool will throw an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask at TOOLBOX → masks → WHWO_unb → mskpin10. This mask includes all areas with ≥ 10% ponderosa-dominated forest within a 1-km radius neighborhood and covers areas where GNN data are available (Washington, Oregon, and northern California). Alternatively, the user may provide a comparable mask that covers their project area or check the "no mask" box, bearing in mind limitations to model applicability described above (see *WHWO unburned forest model applicability*, MODEL APPLICABILITY).

E. Click on OK, the model will run. A series of progress bars will flash. If necessary, close the results window once "succeeded" is displayed. To view the model output, navigate to the output file ("WHWO_unburned_HSI.tif") and select the preview pane tab.

4.3 WHWO instructions for burned forests

The principal output generated by the application tool is a 30m resolution raster layer depicting habitat suitability index (HSI) values, whereby HSI = 0–1 indicate sites least–most suitable for nesting, respectively. The study area must have been burned by relatively large wildfires (1000 acres in western U.S.) for the necessary data to be retrievable. As with all ArcGIS tools, the user can choose among various file extensions indicating format for output layers, of which we recommend ".tif" or ".img" formats for flexibility in file naming. Additional data processing steps will be required if users do not have access to the Forest Service T drive. We provide "optional" data processing instructions for these users.

I. Retrieve and compile data layers. In this step you will process remotely sensed data to compile the variables listed in Table 2.3.2. Pathnames for data files cannot have spaces, so when saving the data layers, ensure that no parent folders in the file path names have spaces. For example, "C:\GIS\Data\White-headed Woodpecker\cancov.tif" is an invalid path name; the folder named "White-headed Woodpecker" needs to renamed to "White-headedWoodpecker" or "WHWO".

A. Follow instructions in Step I.A under *BBWO instructions for the Inland Pacific Northwest* above to retrieve MTBS burn severity data for the wildfire relevant to your project. As noted in the BBWO model instructions, the fire perimeter polygon shapefile will end in "…burn_bndy.shp" and the burn severity raster will end in "…dnbr.tif" (hereafter burn_bndy.shp and dnbr.tif, respectively). **Note on RAVG data: For assessment of recent fires where MTBS data are unavailable, RAVG data can be used instead. We compare HSIs and their predictive performance when produced with MTBS versus RAVG data in Appendix A. RAVG data can be obtained using a different online query tool available at https://www.fs.fed.us/postfirevegcondition/index.shtml. See I.A under 4.4 *Northern Sierra instructions* for retrieving RAVG data.**

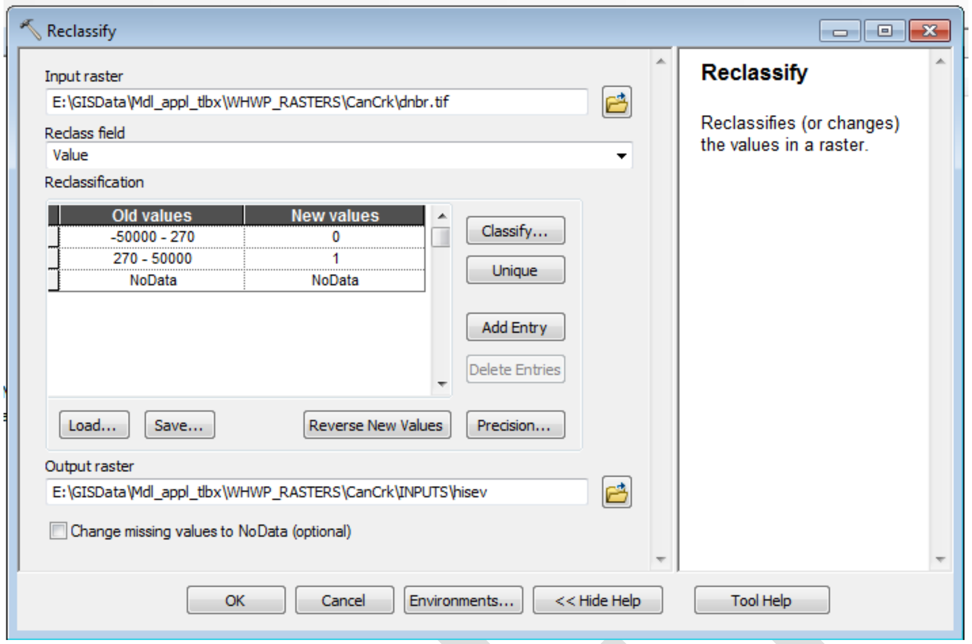
B. Compile the 2 input variables needed for model application (Table 2.3.2) using the associated input generation tool described here. **Note: This input generation tool can only be operated within Forest Service Citrix environment or from an environment with access to the Forest Service T drive. If neither of these conditions are met, follow step I.C for input compilation.** This tool only requires dnbr.tif and burn_bndy.shp files from the user (retrieved in step I.A). This tool only requires the dNBR layer from the user (user retrieves these data in steps I.A), which it combines with default pre-fire canopy cover data to compile inputs. The default canopy cover data represents 2012 gradient nearest neighbor (GNN) data from LEMMA (Landscape Ecology, Modeling, Mapping, and Analysis; *ref*). These data may represent pre-fire canopy cover for wildfires that burned in 2012 or later unless additional disturbance occurred between recording default imagery (after 2011 but before 2012 fire seasons) and the wildfire of interest. We have observed default imagery poorly representing pre-fire canopy cover at some locations for reasons unknown, so users should carefully inspect default canopy cover data to verify they make sense and are reasonably accurate. In cases where default canopy cover data are deemed sufficient, proceed with steps I.B.1–6 to compile input layers. **For wildfires that occurred before 2012 or for which default imagery are unlikely to accurately represent canopy coverage immediately preceding wildfire (e.g., due to additional disturbance in the interceding period), follow steps in I.C to use data from an alternate source.**

1. From ArcCatalog, navigate to the "TOOLBOX → Habitat Suitability Modeling.tbx → Input Development" and open the "Generate Inputs White-headed Woodpecker Burned Model" tool. As stated above, this folder is located at "T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX". Users must either access this location when running ArcCatalog on Citrix or download this entire folder onto their local machine.
2. Identify or create a folder where you want model inputs to be stored. Under "Workspace", navigate to this folder. Then click "Add".
3. For "dNBR", use dnbr.tif downloaded from MTBS (see I.A). Either navigate from outside the tool interface and drag and drop dnbr.tif, or navigate from the "dNBR" box and click "Add".
4. For "Fire Perimeter", navigate to burn_bndy.shp downloaded from MTBS (I.A). You can either navigate from outside the tool interface and drag and drop the burn_bndy.shp into the "Fire Perimeter" box, or navigate from within the tool and click "Add".
5. Click OK (All outputs will be stored in the INPUTS folder in your designated workspace).

6. Close this dialog when completed successfully.

C. *Optional* – Steps for compiling input layers (locbrnopn and landbrnopn) from alternate data sources are described here. **These instructions are for cases where the user lacks access to the Forest Service T drive, or if default canopy cover layers are insufficient for their project area.** These steps assume the user has obtained three layers for their project area: 1) a dnbr.tif file describing burn severity (see I.A), 2) a burn_bndy.shp file delineating the fire perimeter (see I.A), 3) a 30m-pixel raster layer that provides continuous canopy cover (%). Raster layers (1, 3) should cover all areas inside and ≥ 1 km outside burn_bndy.shp. If coverage does not meet this criterion, layers should at least cover all areas within and ≥ 1 km outside study units relevant to management planning or decisions, in which case the user should use a shapefile describing study unit boundaries in place of burn_bndy.shp in step I.C.6 below. Note: We suggest following file naming directions to more easily keep track of files referenced in these instructions.

1. Identify or create a folder named "INPUTS" in your workspace. Place intermediate and final layers generated from steps I.C.2–6 below in this folder. The remainder of these steps will refer to this folder as the INPUTS folder.
2. Classify dnbr.tif (see I.A) to generate intermediate "hisev.tif" layer.
    a. Open the Reclassify tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Reclassify).
    b. Designate dnbr.tif as the "Input Raster". Adjust the "Reclassification" table to match the image below to generate two classes: value = 0 for dNBR < 270 and value = 1 for dNBR > 270.

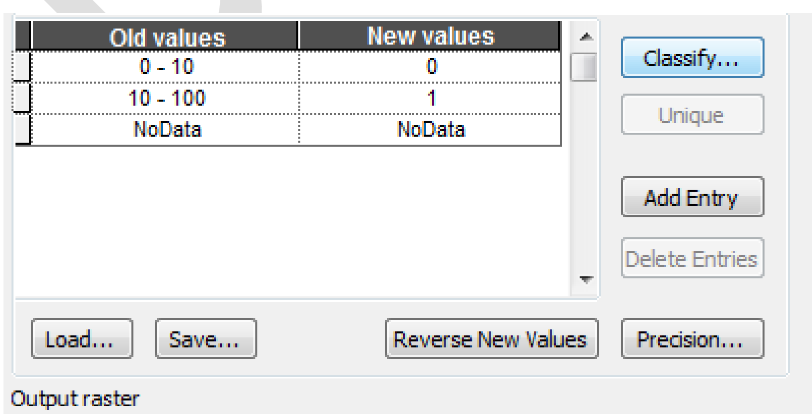


c. Browse to your INPUTS folder and name the output file “hisev.tif”.

3. Classify your continuous canopy cover layer (see I.C; hereafter “cancov.tif”) to generate intermediate “ccopen.tif” layer.

   a. Open the Reclassify tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Reclassify).

   b. Designate “cancov.tif” as the “Input Raster”. Adjust the “Reclassification” table to match the image below to generate two classes: value = 1 for cancov < 10 and value = 0 for cancov > 10.

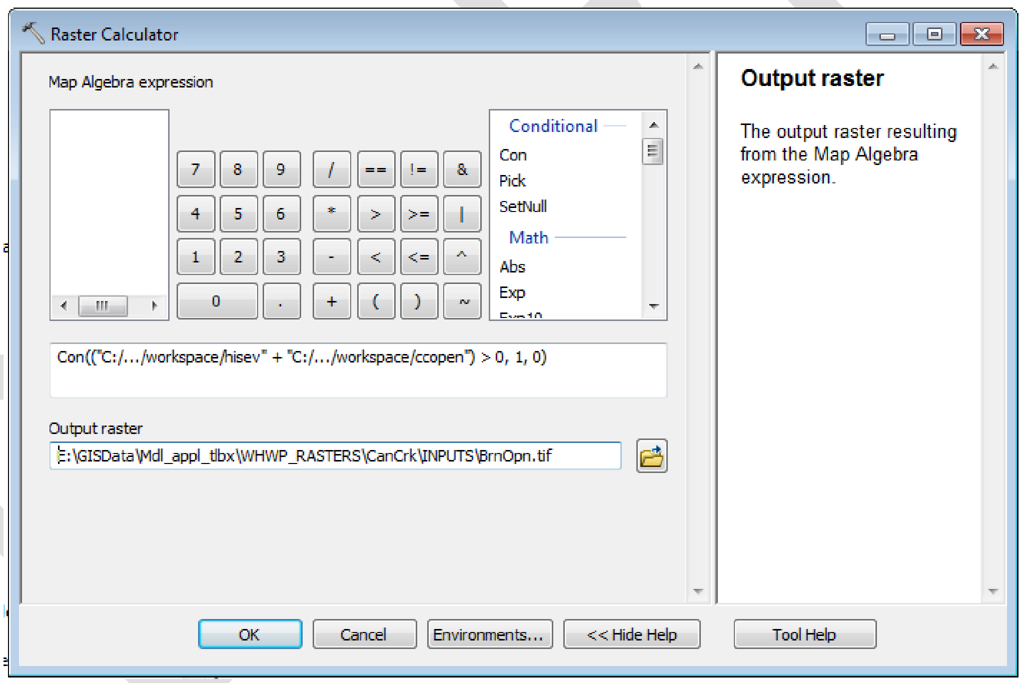


c. Browse to your INPUT folder and name the output file “ccopen.tif”. Click OK.

4. Calculate burn or open later.

   a. Open the “Raster Calculator” tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Raster Calculator).

   b. In the expression box, write a statement that adds “ccopen” (I.C.3) and “hisev” (I.C.2), and then assigns ‘1’ to pixels when ccopen + hisev > 0 and ‘0’ when ccopen + hisev = 0 using the ‘Con’ function. The final expression will be of the form ‘Con((“workspace/hisev.tif” + “workspace/ccopen.tif”) > 0, 1, 0)’ (see example screen shot below).



   c. Name the output raster “BrnOpn.tif” and set its location to your INPUTS folder. Click OK.

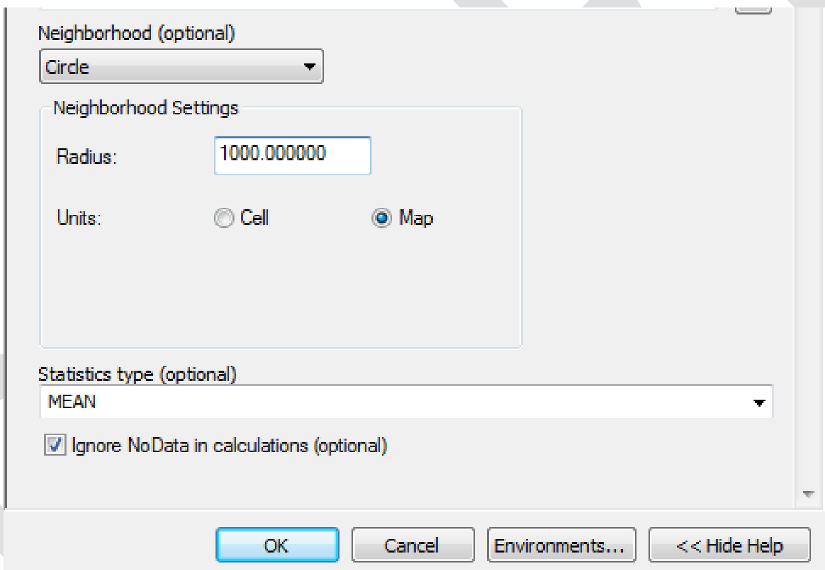
5. Apply the “Focal Statistics” to “BrnOpn.tif” (see previous step) and further process with “Raster Calculator” to generate layers describing percent area burned or open.

a. Open the Focal Statistics tool (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Focal Statistics).

b. Designate “BrnOpn.tif” as the “Input Raster”.

c. Apply the default neighborhood of 3×3 cells with “Statistics type” set to “Mean”. Name the resulting layer “locbrnopn_prp.tif”.

d. Run the Focal Statistics tool again (Repeat I.C.5.a–b), this time setting the neighborhood to “circular” and size to radius = 1000 and units = “Map”. Set Statistics type = “Mean” (see below screenshot). Name the resulting layer “landbrnopn_prp.tif”.

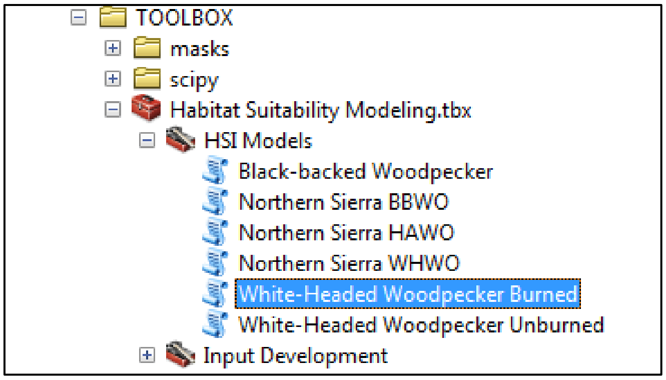


e. For each layer generated in the last step (“locbrnopn_prp.tif” and “landbrnopn_prp.tif”), apply the Raster Calculator tool again (TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Raster Calculator) to rescale to percentages, i.e., multiple “locbrnopn_prp.tif” and “landbrnopn_prp.tif” by 100. Set output filenames to “locbrnopn_premask.tif” and "landbrnopn_premask.tif", respectively, and set their locations to your INPUT folder.

6. Clip percent area (burned or open) layers to the fire perimeter to produce final input layers. Open TOOLBOX → Habitat Suitability Modeling.tbx → Input Development → Extract by Mask. Successively designate layers generated in the previous step ("locbrnopn_premask.tif" and "landbrnopn_premask.tif") as Input layers and burn_bndy.shp as the mask. Designate the INPUTS folder as the output location and name the output files "locbrnopn.tif" and "landbrnopn.tif". For "landbrnopn.tif", set the snapping layer (Under "Environments… → Processing Extent → Snap Raster" at the bottom of the "Extract by Mask" window) to "locbrnopn.tif" to ensure both layers are snapped together.
7. To remain organized and ensure input layers can be easily located in the future, delete all intermediate layers (hisev.tif, ccopen.tif, BrnOpn.tif, locbrnopn_prp.tif, landbrnopn_prp.tif, locbrnopn_premask.tif, and landbrnopn_premask.tif) or move them to another appropriate location (e.g., a subfolder named "intermediates" in your INPUTS folder or workspace).

II. Run model application tool

A. From ArcCatalog, navigate to "TOOLBOX → Habitat Suitability Modeling.tbx → HSI Models" and open the "White-headed Woodpecker Burned" tool.

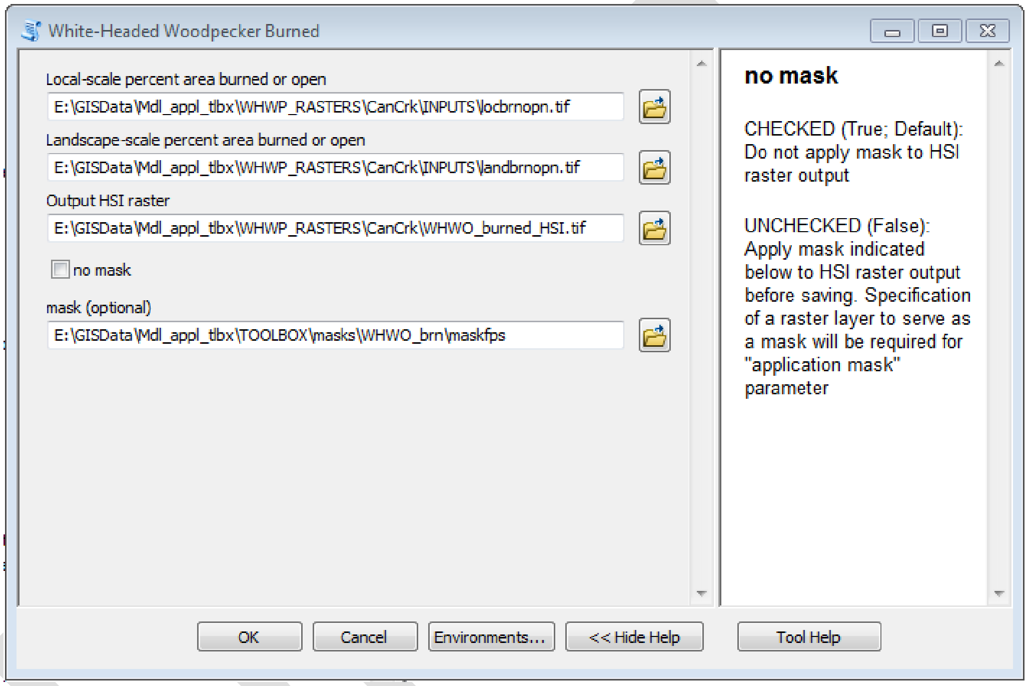


B. For “Local-scale percent area burned or open” and “Landscape-scale percent area burned or open”, use “locbrnopn.tif” and “landbrnopn.tif” input rasters, respectively (see steps under I.A–C above). Either navigate to the INPUTS folder from outside the tool dialog box and drag and drop each input layer, or navigate from within the dialog box and click “Add” to designate each layer.

C. For “Output HSI raster”, designate an appropriate location and filename for the output raster. Click the button with the folder icon to the right, locate your workspace, and create a meaningful name, e.g., “WHWO_burned_HSI.tif”. Again, alternate file formats available for rasters can be specified, but we recommend “.img” or “.tif” because these allow longer filenames than the default ArcGrid format (designated by leaving off any filename extension).

D. Select masking option. The user must have either the “no mask” box checked or provide a raster layer to serve as a mask for the final HSI output layer. If neither is true, the tool will throw an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask at TOOLBOX → masks → WHWO_brn → maskfps. This mask includes all areas characterized as dry conifer forest with ≥10% ponderosa-dominated forest within a 1-km radius neighborhood and

≤40% slope. The mask only covers areas where GNN data are available (Washington, Oregon, and northern California). Alternatively, the user may provide a comparable mask that covers their project area or check the "no mask" box, bearing in mind limitations to model applicability described above (see *WHWO burned forest model applicability*, MODEL APPLICABILITY). With a mask selected, the input window for this tool will resemble the screenshot below.



E. Click on OK, the model will run. A series of progress bars will flash. If necessary, close the results window once "succeeded" is displayed. To view the model output, navigate to the output file ("WHWO_burned_HSI.tif") and select the preview pane tab.

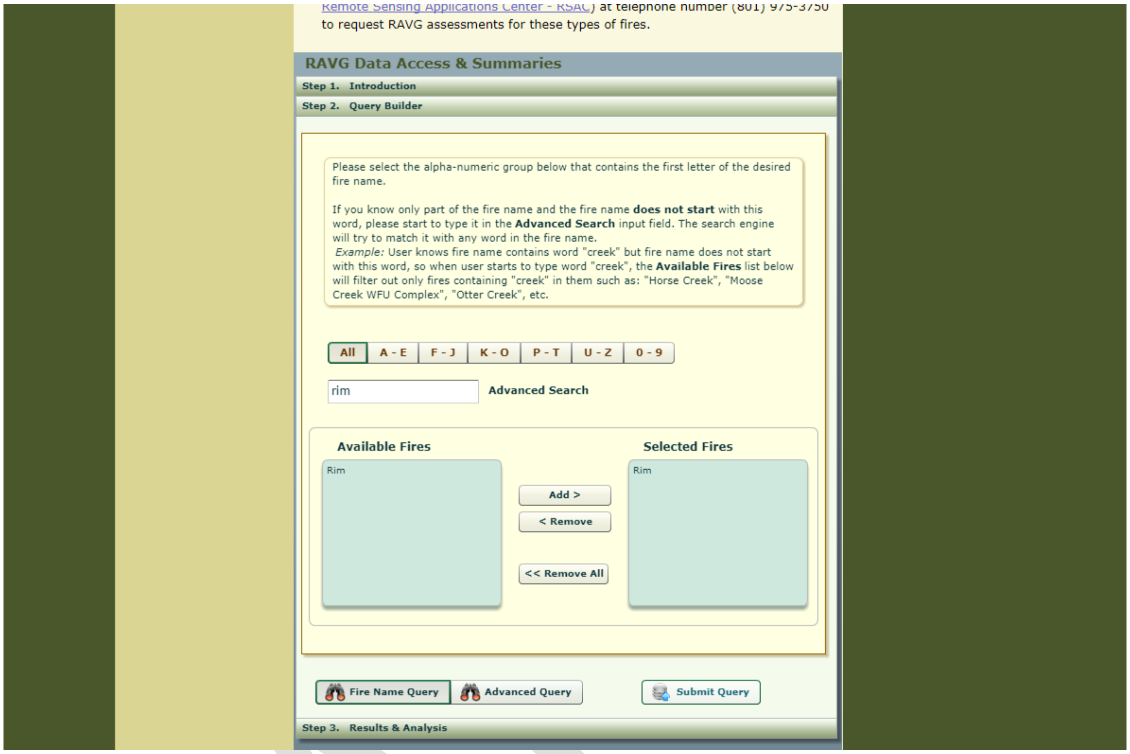
4.4 Northern Sierra instructions

We provide three model application tools (one per species) for northern Sierra Nevada Mountain forests. Outputs generated by these tools are 30m raster layers with HSI values ranging from 0 to 1. As for other tools, we recommend using ".tif" or ".img" extensions for output layers for flexibility in filename length. The study area must have been burned by sufficiently large wildfires (>1000 acres) for the necessary data to be retrievable.

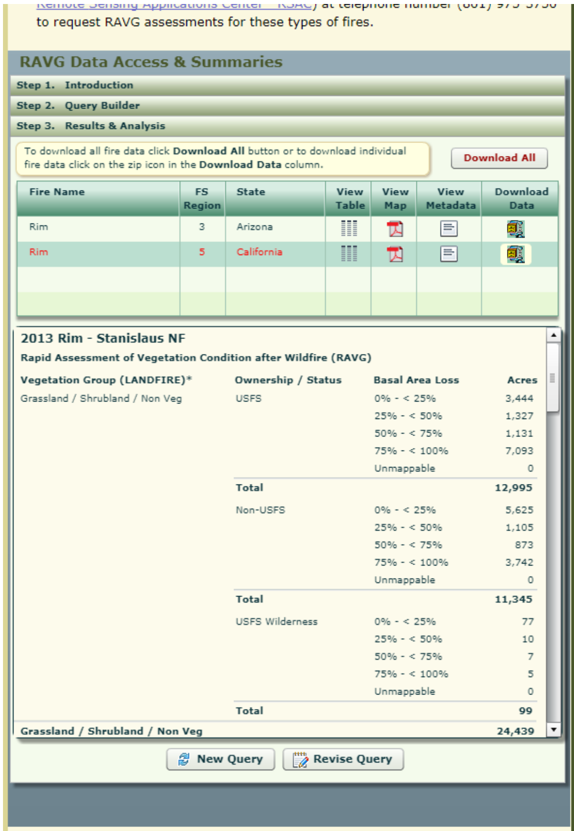
I. Retrieve and compile environmental data layers. In this step you will retrieve remotely sensed data from USFS websites and input them into the Input Generation Tool to compile the variables listed in Table 2.4.2. None of the files you download will need to be altered from their downloaded form. The pathnames for data files used in these tools cannot have spaces, so when saving the environmental data layers to your workstation below, ensure that no parent folders in the file path names have spaces. For example, “C:\GIS\Data\Northern Sierra\rdnbr_cc.tif” is an invalid path name; the folder named “Northern Sierra” needs to renamed to “NorthernSierra” or “Northern_Sierra”.

   A. Retrieve burn severity data:

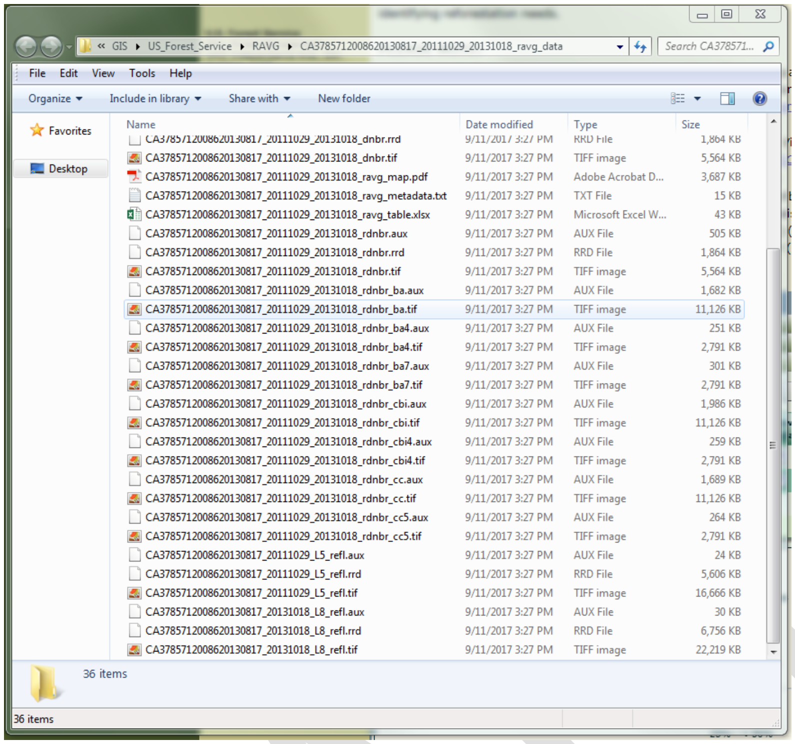
      1. Go to the USFS Post-Fire Vegetation Conditions website https://www.fs.fed.us/postfirevegcondition/index.shtml and enter the necessary information for your fire in the query builder. In this example, we are looking for the 2013 Rim Fire in California. If a window like the one below is not visible in your web browser at the webpage linked to above, ensure that Adobe Flash Player is enabled in your web browser then refresh the webpage.



2. Click on the compressed file icon under the Download Data column to download the GIS data packet for your fire, then unzip the contents into your GIS workspace.



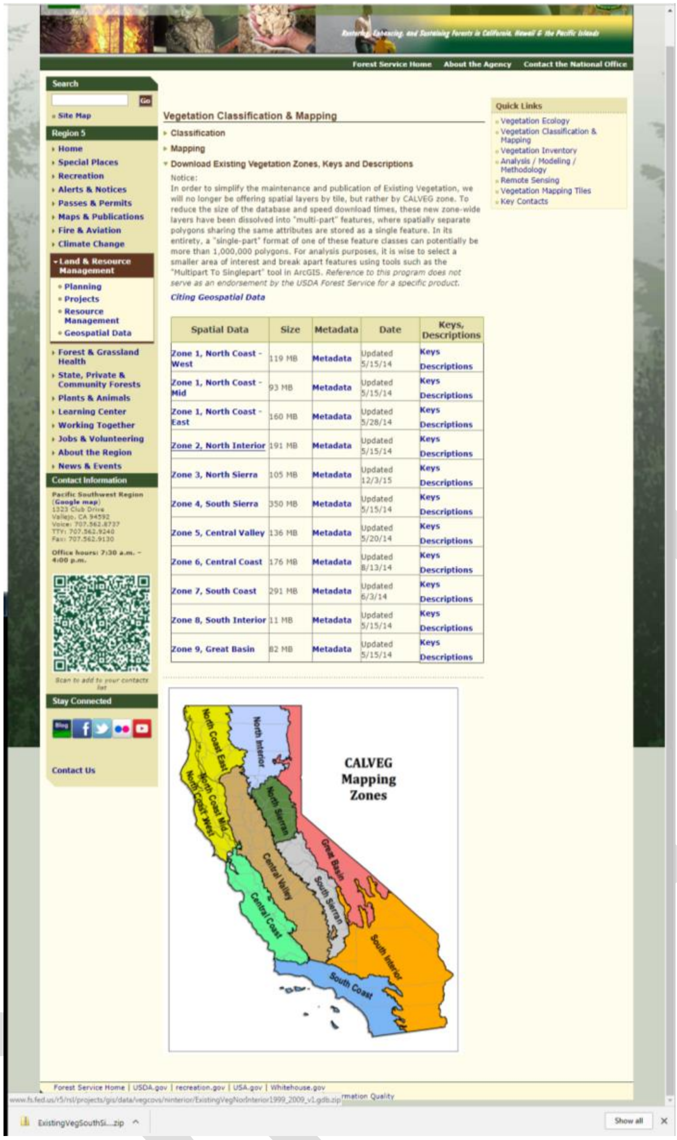
3. See the metadata document in the extracted file folder for explanation of the files associated with your download. In general, the fire perimeter polygon shapefile will end in "…burn_bndy…" and the burn severity raster will end in "_cc_alb.tif" or "_cc.tif" (hereafter "fire perimeter" and "burn severity" layers, respectively).



B. Retrieve pre-fire forest structure data:

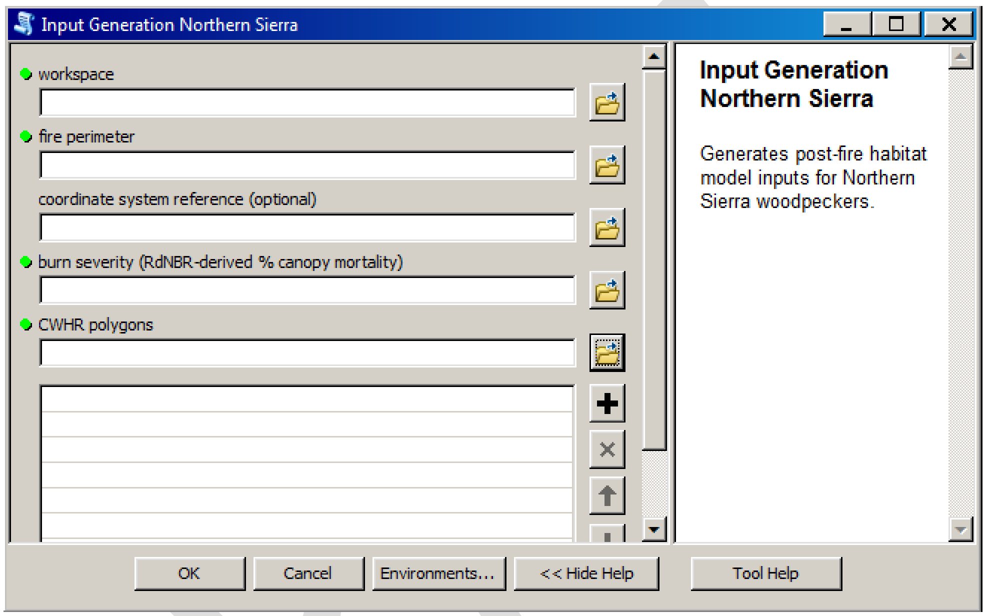
1. Navigate to the Region 5 Vegetation Classification and Mapping webpage https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192, then click on "Download Existing Vegetation Zones, Keys and Descriptions."

2. A table will appear below. Click on the Zone containing your fire of interest under the Spatial Data column of the table. If your fire of interest is near the border of a Zone, you may also need to download the adjacent Zone to get complete coverage of the fire perimeter and a 1-km buffer area outside the perimeter. Unzip the file and place the geodatabase into your GIS workspace.



C. Now you will compile the input variables needed to apply any of the habitat models for Northern Sierra woodpeckers (Tables 2.4.2, 2.4.5) using the associated Input Generation Northern Sierra tool. The following subtasks are best preformed entirely from ArcCatalog. **Unlike for other toolsets, the input generation tool for Northern Sierra woodpeckers does not require access to data layers on the T drive and therefore can be operated in any environment following retrieval of raw data as described in Steps 1.A and 1.B.**

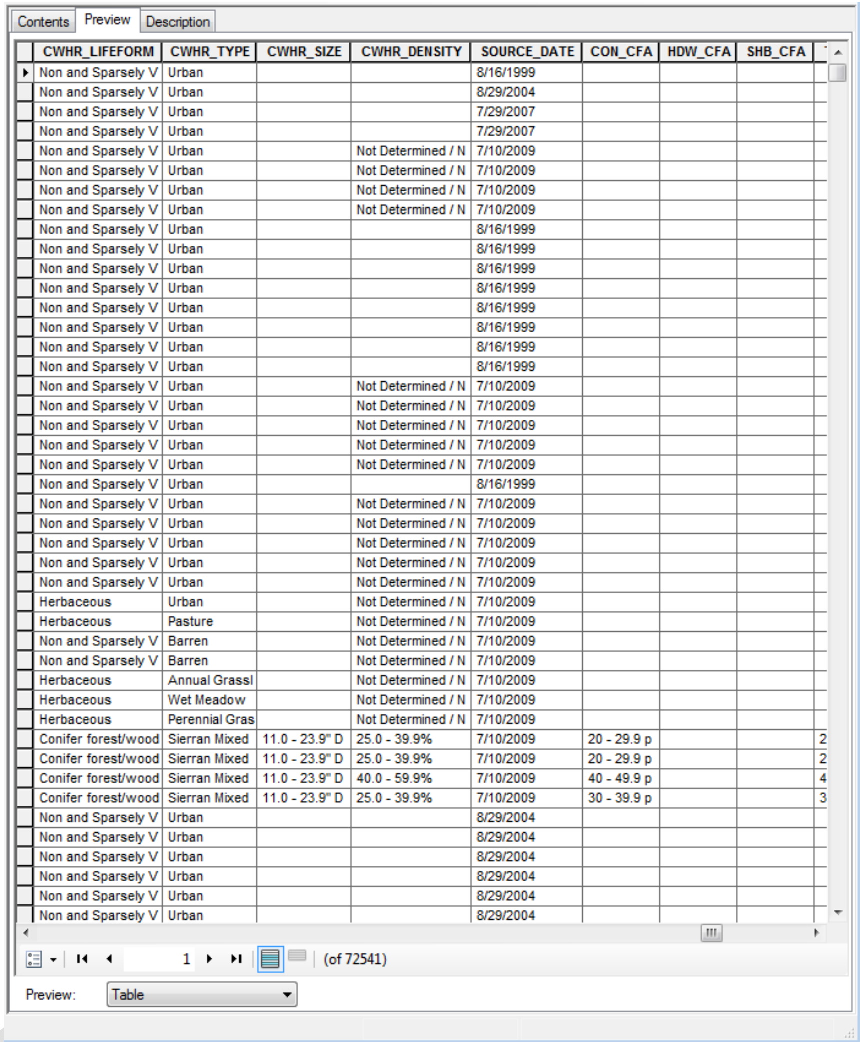
1. From ArcCatalog, navigate to the "TOOLBOX → Habitat Suitability Modeling.tbx → Input Development" and open the "Input Generation Northern Sierra" tool by double-clicking it. This folder is located at "T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\TOOLBOX" on Citrix or the "TOOLBOX" folder extracted to your local workstation.



2. Identify or create a folder where you want the layers generated from this tool to be stored. Under "workspace", navigate to this folder. Then click "Add". Alternatively, you can drag and drop the desired folder to this window from ArcCatalog.
3. For "fire perimeter", navigate to the fire perimeter shapefile downloaded along with RAVG data. You can either navigate from outside the tool interface and drag and drop the perimeter shapefile into the "Fire Perimeter" box from ArcCatalog, or navigate from within the tool and click "Add".
4. If the user desires the output file to be in a different coordinate system from RAVG data (i.e., the fire perimeter shapefile), provide a spatial layer (shapefile or raster) that

represents the desired coordinate system (drag and drop or navigate from within the tool). Otherwise, leave blank.

5. For “burn severity”, use the % canopy mortality layer downloaded with RAVG data (steps I.A; drag and drop or navigate from within the tool). The filename for this layer may vary but should include “cc” (e.g. “_cc.img”, “_cc.tif”, or “_cc_alb.tif”) and not “cc5”. The user may need to review metadata for downloaded layers (click on the “Description” tab when previewing in ArcCatalog) to identify the right layer. The values in the % canopy mortality layer are derived from relativized delta-normalized burn ratio (RdNBR) and should range 0–100. If no such layer exists, the user may contact the Region 5 Remote Sensing Laboratory for an appropriate file.
6. For “CWHR polygons”, provide the Existing Vegetation polygon file(s) retrieved in Step I.B (drag and drop or navigate from within the tool). The attribute table for each polygon file should contain “CWHR_DENSITY” and “CWHR_SIZE” fields, from which input layers are derived. Users can verify existence of these fields by previewing the attribute table for each polygon file in ArcCatalog (go to “Preview” tab at the top and select “Table” in the drop down menu at the bottom and scroll to the right, e.g., see screen shot below).


Contents | Preview | Description

CWHR_LIFEFORM	CWHR_TYPE	CWHR_SIZE	CWHR_DENSITY	SOURCE_DATE	CON_CFA	HDW_CFA	SHB_CFA	
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/29/2004				
Non and Sparsely V	Urban			7/29/2007				
Non and Sparsely V	Urban			7/29/2007				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban			8/16/1999				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Non and Sparsely V	Urban		Not Determined / N	7/10/2009				
Herbaceous	Urban		Not Determined / N	7/10/2009				
Herbaceous	Pasture		Not Determined / N	7/10/2009				
Non and Sparsely V	Barren		Not Determined / N	7/10/2009				
Non and Sparsely V	Barren		Not Determined / N	7/10/2009				
Herbaceous	Annual Grassl		Not Determined / N	7/10/2009				
Herbaceous	Wet Meadow		Not Determined / N	7/10/2009				
Herbaceous	Perennial Gras		Not Determined / N	7/10/2009				
Conifer forest/wood	Sierran Mixed	11.0 - 23.9" D	25.0 - 39.9%	7/10/2009	20 - 29.9 p			2
Conifer forest/wood	Sierran Mixed	11.0 - 23.9" D	25.0 - 39.9%	7/10/2009	20 - 29.9 p			2
Conifer forest/wood	Sierran Mixed	11.0 - 23.9" D	40.0 - 59.9%	7/10/2009	40 - 49.9 p			4
Conifer forest/wood	Sierran Mixed	11.0 - 23.9" D	25.0 - 39.9%	7/10/2009	30 - 39.9 p			3
Non and Sparsely V	Urban			8/29/2004				
Non and Sparsely V	Urban			8/29/2004				
Non and Sparsely V	Urban			8/29/2004				
Non and Sparsely V	Urban			8/29/2004				
Non and Sparsely V	Urban			8/29/2004				
Non and Sparsely V	Urban			8/29/2004				

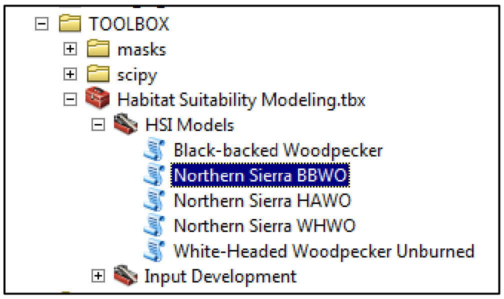
1 (of 72541)

Preview: Table

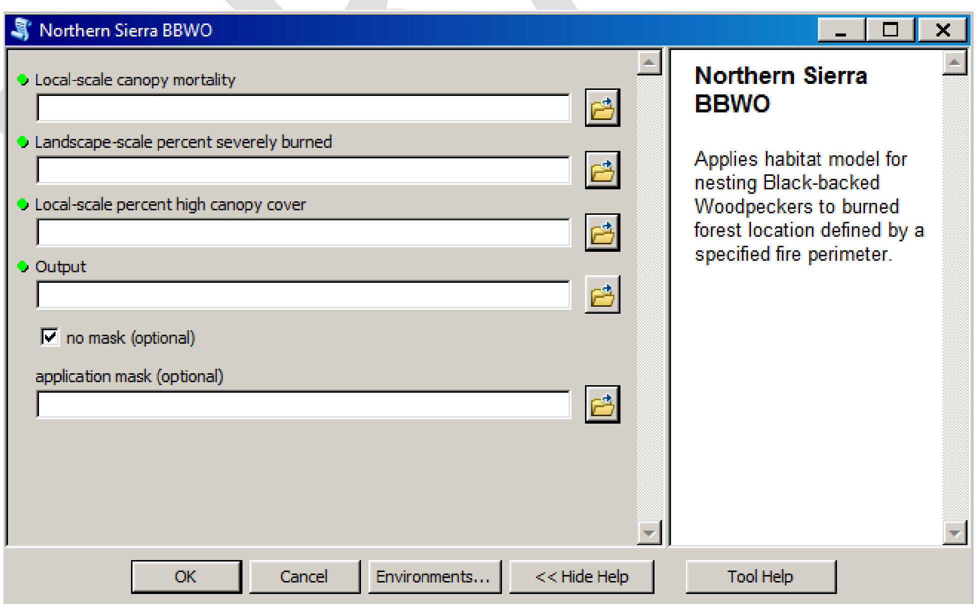
7. Click OK. All outputs will be stored under “predictors” in your designated workspace. Open this folder and verify presence of the following layers: “locccmort.tif”, “landccmort.tif”, “loccc.tif”, “landcc.tif”, “loctrsize.tif”.
8. Optional: The “_scratch” directory generated in the designated workspace when implementing this tool can be deleted upon successful completion.

II. Run any or all model application tool as desired. Now you will use the layers in the predictors file above as inputs for the species-specific habitat suitability models for Northern Sierra woodpeckers. The following tasks are best preformed entirely from ArcCatalog.

A. From ArcCatalog, navigate to "TOOLBOX →Habitat Suitability Modeling.tbx", open the "HSI models" toolbox, and then open the desired tool named "Northern Sierra…," e.g., "Northern Sierra BBWO," by double-clicking it.



B. For the variables listed in Table 2.4.2 (abbrv: LocCCmort, LandCCmort, LocCC, LandCC, and LocTrSize), use "locccmort.tif", "landccmort.tif", "loccc.tif", "landcc.tif", "loctrsize.tif", respectively (generated in Step I.C). Either navigate to the "predictors" folder in ArcCatalog and drag and drop each input layer, or navigate from within the dialog box and click "Add" to designate each layer. A subset of 2-3 of these input layers will be required for any one tool.



C. For the "Output" parameter, designate an appropriate location and filename for the output HSI raster. Click the button with the folder icon to the right, locate your workspace or any other desired location, and create a meaningful name, e.g., "HSI_BBWO.tif". Again, we recommend ".img" or ".tif" file extensions to allow longer filenames.

D. Select masking options. The user must either check the "no mask" box or provide a raster layer to serve as a mask for the final HSI output layer. If neither is done, the tool will produce an error. Any raster layer can function as a mask, whereby pixels in the mask layer with NODATA will indicate which values to be dropped (i.e., converted to NODATA) in the final HSI output. We provide a potential mask whose rationale is described in *Applicability of Northern Sierra models* under MODEL APPLICABILITY above (TOOLBOX → masks → NSierra → mask). If this mask includes the entire study area (i.e., study area contains no NODATA pixels), the user may check the "no mask" box and proceed with tool implementation. On the other hand, if large portions of the study area are excluded, the safest course would be to specify the suggested mask or an equivalent layer relevant to the user's project area.

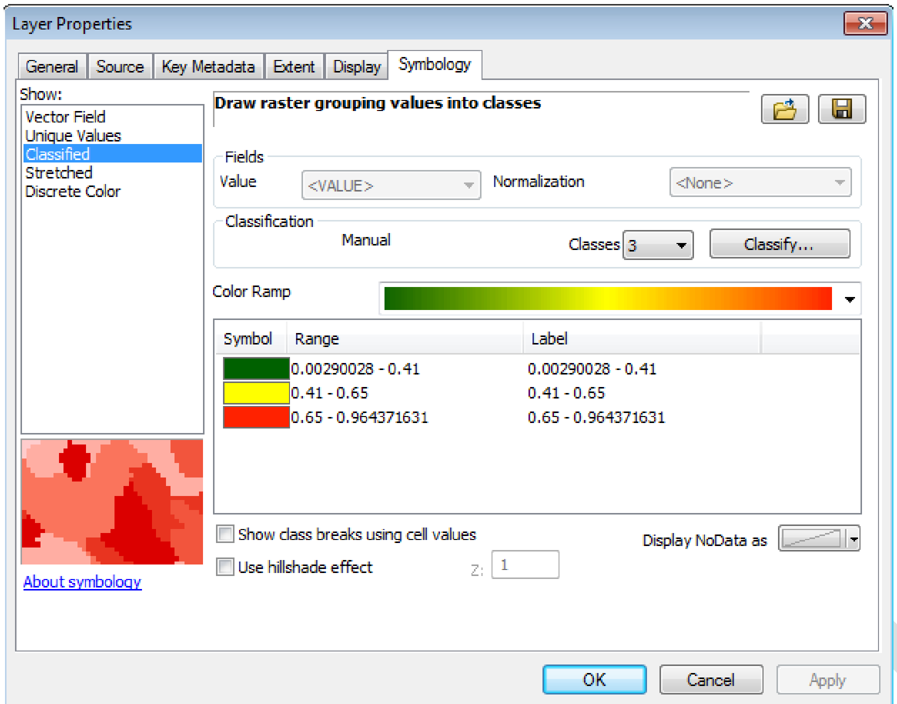
E. Click on OK to run the model. A series of progress bars will flash. If necessary, close the results window once "succeeded" is displayed. To view the HSI model output, navigate to the file named in step II.C (e.g., "HSI_BBWO.tif"), and then select preview pane to preview the HSI map.

5. GUIDELINES FOR HSI APPLICATION AND INTERPRETATION

We provide both general and model-specific guidelines for displaying and applying HSI maps to inform forest planning. In general, we anticipate forest managers will need to display model predictions as suitability categories (e.g., low, moderate, and high suitability habitat). We therefore focus here on defining and interpreting such categories.

In general, HSI maps depicting suitability categories can be displayed in ArcMap following these steps:

1. In ArcMap, either open a new map document or an existing one containing relevant layers for project planning.
2. Open the Catalog window (look for  button).
3. From the Catalog window, navigate to the output HSI map layer generated from the model application tool (e.g., "BBWO_..._HSI_ensemble_output.tif", "HSI_HAWO.tif"), and drag and drop this layer into the ArcMap table of contents window (left hand side of screen).
4. In ArcMap Table of Contents, right-click on the HSI output layer and go to Properties → Symbology. Select the "Classified" option in the menu on the left.



From this window, select the number of categories desired, the HSI thresholds that define desired categories (click on the "Classify" button on the right), and the color scheme for mapping. We provide guidance for defining categories for particular models below.

We expect three basic questions facing forest managers with woodpecker habitat conservation objectives:

1. Where is suitable nesting habitat within the project area?
2. Where and how could management activities positively or negatively impact habitat?
3. How much suitable habitat is needed for population persistence?

To help address these questions, we relate HSIs with nest densities observed at locations where models were developed. We relate HSIs with either apparent or hatched nest densities to inform suitability categories and their interpretation. Apparent nest densities are subject to negative detection bias, but we expect this bias to be sufficiently independent of habitat for apparent densities to accurately reflect HSI-related variation and differences among suitability classes. Hatched nests are highly detectable, so we expect detection bias to be negligible given our survey methods (Russell et al. 2009). We generated 95% CIs for apparent or hatched nest densities within suitability categories using non-parametric bootstrapping (Efron and Tibshirani 1986) with transects (Northern Sierra and WHWO unburned-forest models) or 600-m cells (BBWO and WHWO burned-forest models) as sampling units. We caution that density estimates may not fully account for regional variation in population density or time since disturbance. Nevertheless, they indicate differences in nest densities among low, moderate, and high suitability habitat at sampled locations within five years following wildfire. In addition, we provide a hypothetical worked example of model application to inform forest planning at the Canyon Creek Fire in the Malheur National Forest (Appendix XX).

Habitat suitability models provided here only describe the relative suitability of sites for nesting, and therefore cannot be used in isolation to inform how much habitat to conserve (Question 3). To address this question, managers must consider population ecology and management objectives along with the distribution of modeled habitat. Relating HSIs with nest densities can help inform applications with particular population targets. Ideally, we would relate additional population parameters, such as abundance, fitness, and population viability, with habitat to develop meaningful management objectives. Such data are often unavailable and prohibitively costly to collect for most woodpecker populations, however. We therefore instead suggest a comparative approach to inform forest planning. We can compare the amount of highly or moderate-to-highly suitable habitat retained among alternative management scenarios, relative to what was present historically across landscapes of interest. The aim of management objectives founded on a comparative approach would be to maintain levels of habitat associated with persistent populations in other areas or time periods. Continued testing and refinement of models with newly acquired independent data could improve model predictive performance, which would concomitantly improve the information provided by this approach.

5.1 Guidelines for post-fire habitat models

We expect application of post-fire habitat models primarily to inform management plans needing to accommodate both resource extraction (i.e., salvage logging) and woodpecker habitat conservation. To support such application, we identify suitability categories based on HSI relationships with observed nest densities (not corrected for imperfect detection) or densities of hatched nests (highly detectable; Russell et al. 2009) in burned forests where models were developed (see also Latif et al. 2013, Campos et al. In Prep). In all cases, observed nest densities increased from low to moderate and moderate to high suitability classes (Tables 5.1.1–5.1.3, Figures 5.1.1–5.1.3). Our observations suggest some variation among study locations (Tables 5.1.1). Nevertheless, nest densities consistently increased with increasing model-predicted suitability. Reserves set aside for habitat conservation should therefore proportionately favor areas classified high over moderate and moderate over low suitability.

Table 5.1.1. Observed nest densities (per 1000 ac) at locations habitat suitability models were developed for nesting Black-backed Woodpeckers. Low, moderate, and high suitability classes correspond with ensemble model predictions of 0–2, 3–5, and 6–8, respectively. Percent nests = the expected value given even sampling across categories. Area surveyed represents the extent surveyed each year multiplied by study duration at each location. 95% confidence limits (error bars) were bootstrapped using 600 m cells as sampling units (*n* = 67, 83, and 176 for Star Gulch, Tripod, and Toolbox locations, respectively).

Location	Quantity	Habitat suitability (HSI) class		
		Low	Moderate	High
Star Gulch	Density	0.22 (0,0.56)	2.07 (0.32,4.51)	3.92 (2.55,5.35)
	Percent nests	4 (0,10)	33 (7,54)	63 (45,89)
	Area surveyed (ha)	8993.6	2896.2	6887.4

Tripod	Density	0 (0,0)	1.96 (0,4.72)	9.86 (4.3,16.1)
	Percent nests	0 (0,0)	17 (0,43)	83 (57,100)
	Area surveyed (ha)	5092.8	1020.2	1520.9
Toolbox	Density	1.28 (0.41,2.26)	5.92 (3.41,8.84)	11.03 (8.38,13.93)
	Percent nests	7 (2,12)	32 (21,44)	61 (49,73)
	Area surveyed (ha)	4690.7	3210.7	6434.6
All[a]	Density	0.43 (0.16, 0.75)	3.57 (2.18, 5.17)	7.71 (6.25, 9.33)

[a]Values represented in Figure 5.1.1.

Figure 5.1.1. Observed nest densities related to ensemble habitat suitability index (HSI; i.e., the number of models classifying a given site suitable) for Black-backed Woodpeckers in the Inland Northwest. Small black dots are values for individual HSI levels. Large red dots represent observed densities averaged (mean) across locations (Star Gulch, Toolbox, and Tripod) within suitability categories (low, moderate, and high) and are plotted at mean HSI values. 95% confidence limits (error bars) were bootstrapped using 600 m cells as sampling units (n = 326 across all three locations).

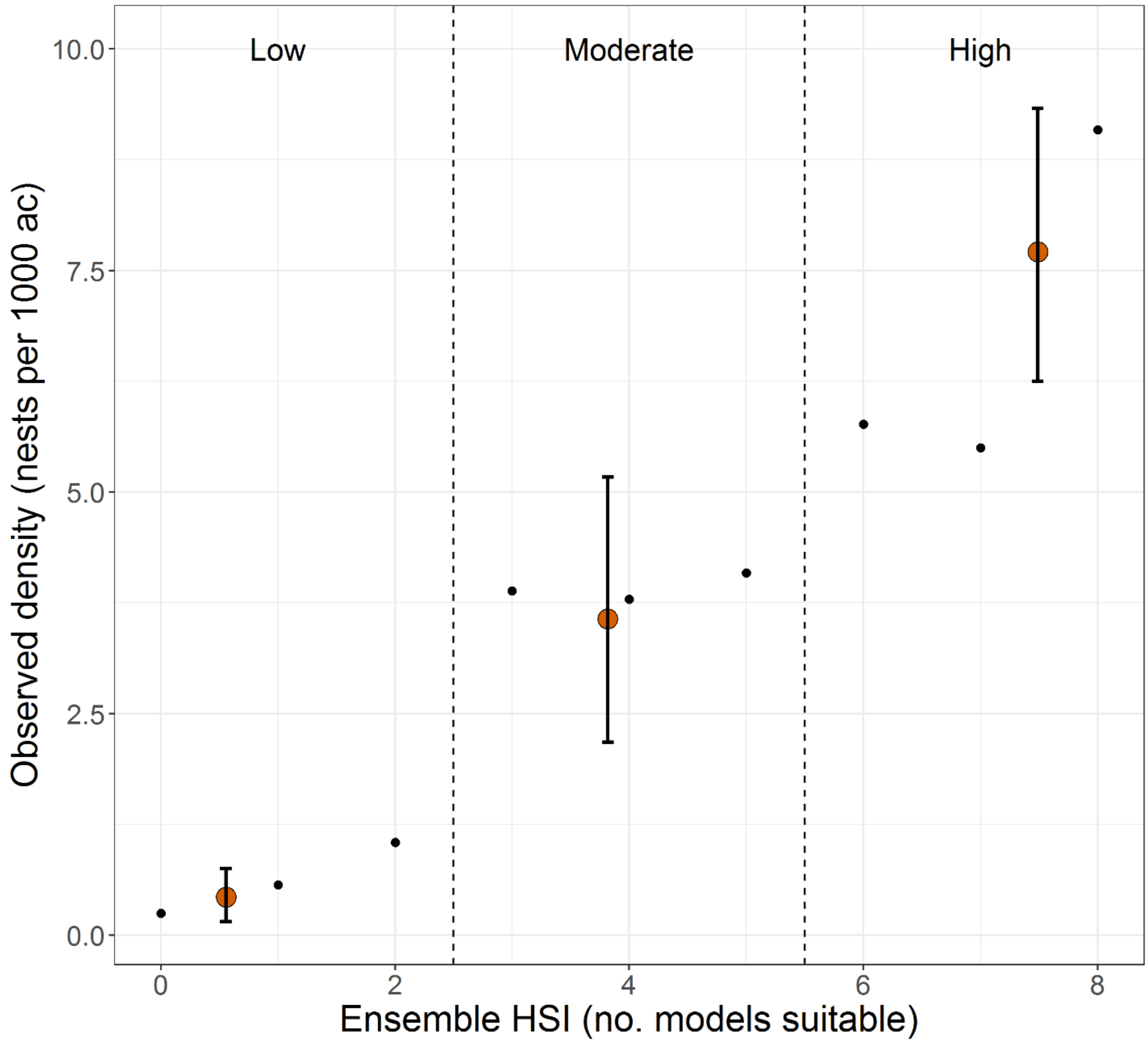


Table 5.1.2. Density of hatched nests (per 1000 ac) in suitability classes defined by HSI thresholds (0.34, 0.6) for White-headed Woodpeckers in burned forest. Models were developed with data from Toolbox and Canyon Creek wildfire locations (Oregon). 95% CLs (in parentheses) were generated with non-parametric bootstrapping. Values for "percent nests" are the expected percent of hatched nests assuming equal area sampling across suitability classes. Area surveyed was calculated as the proportion of sites representing the surveyed area in each suitability class multiplied by the total area surveyed at each location.

Location	Quantity	Habitat suitability (HSI) class		
		Low	Moderate	High
Toolbox	Density	0.28 (0.06,0.54)	1.52 (0.9,2.2)	3.97 (1.93,6.22)
	Percent nests	5 (1,10)	26 (16,43)	69 (50,80)
	Area surveyed (ac)	17592.3	15765.1	3780.7
Canyon Creek	Density	0.66 (0.23,1.2)	3.11 (1.99,4.3)	6.12 (2.71,10.11)

	Percent nests	7 (2,14)	31 (19,50)	62 (41,76)
	Area surveyed (ac)	12114.4	8673.8	1633.4
Both[a]	Density	0.44 (0.21,0.71)	2.09 (1.49,2.7)	4.68 (2.91,6.68)

[a]Values represented by red circles and error bars in Figure 5.1.2.

Figure 5.1.2. Densities of hatched nests for White-headed Woodpeckers along habitat suitability index (HSI) gradient in burned forest. Low, moderate, and high suitability classes are differentiated by two HSI thresholds, one that maximizes the sum of sensitivity and specificity (maxSSS) and the other placed at a natural break in densities for equal-area moving window bins in this figure (small dots) and the distribution of nest site HSIs (rug bars). Large circles and error bars are density estimates and bootstrapped 95% CIs for habitat suitability classes.

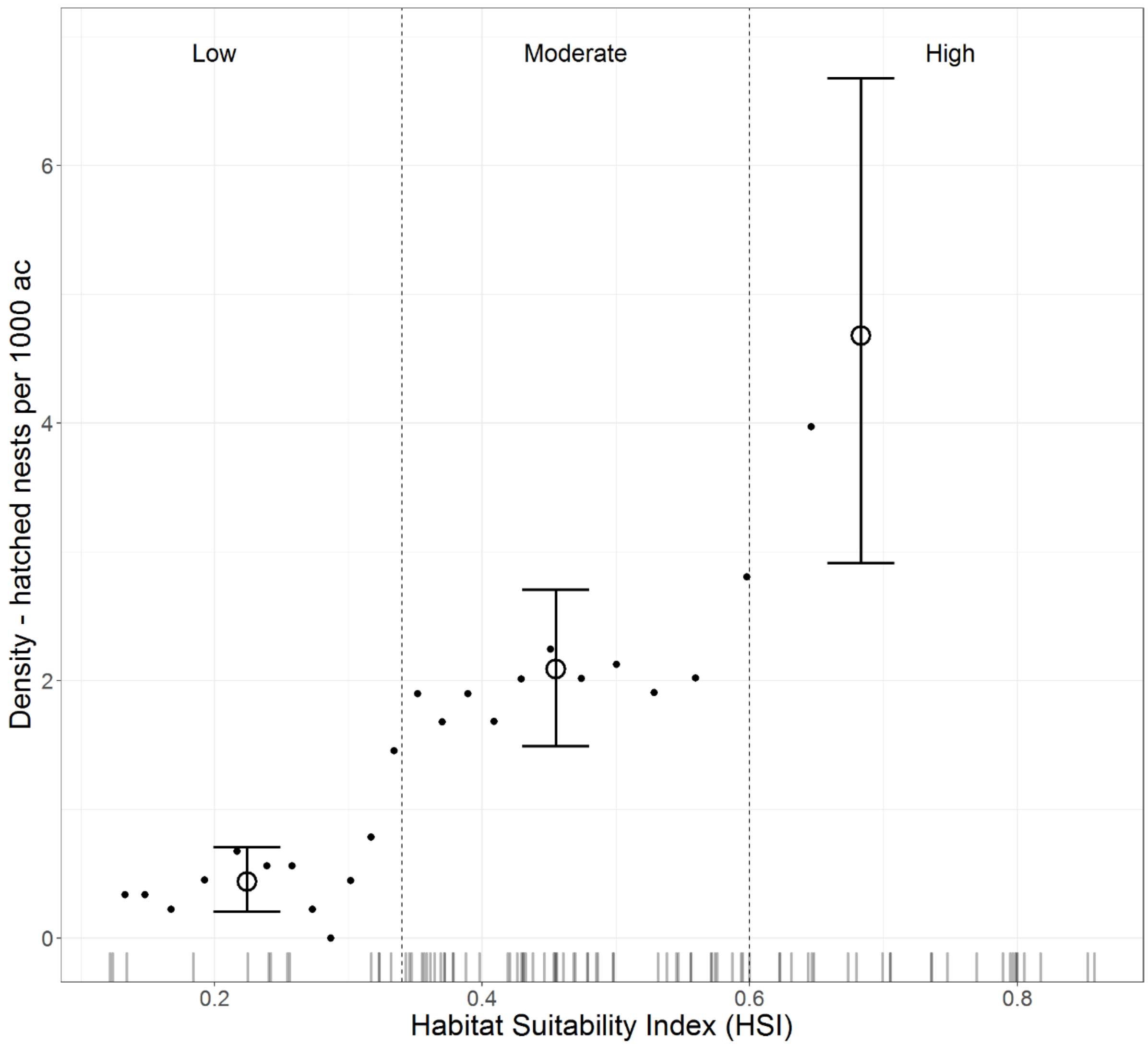
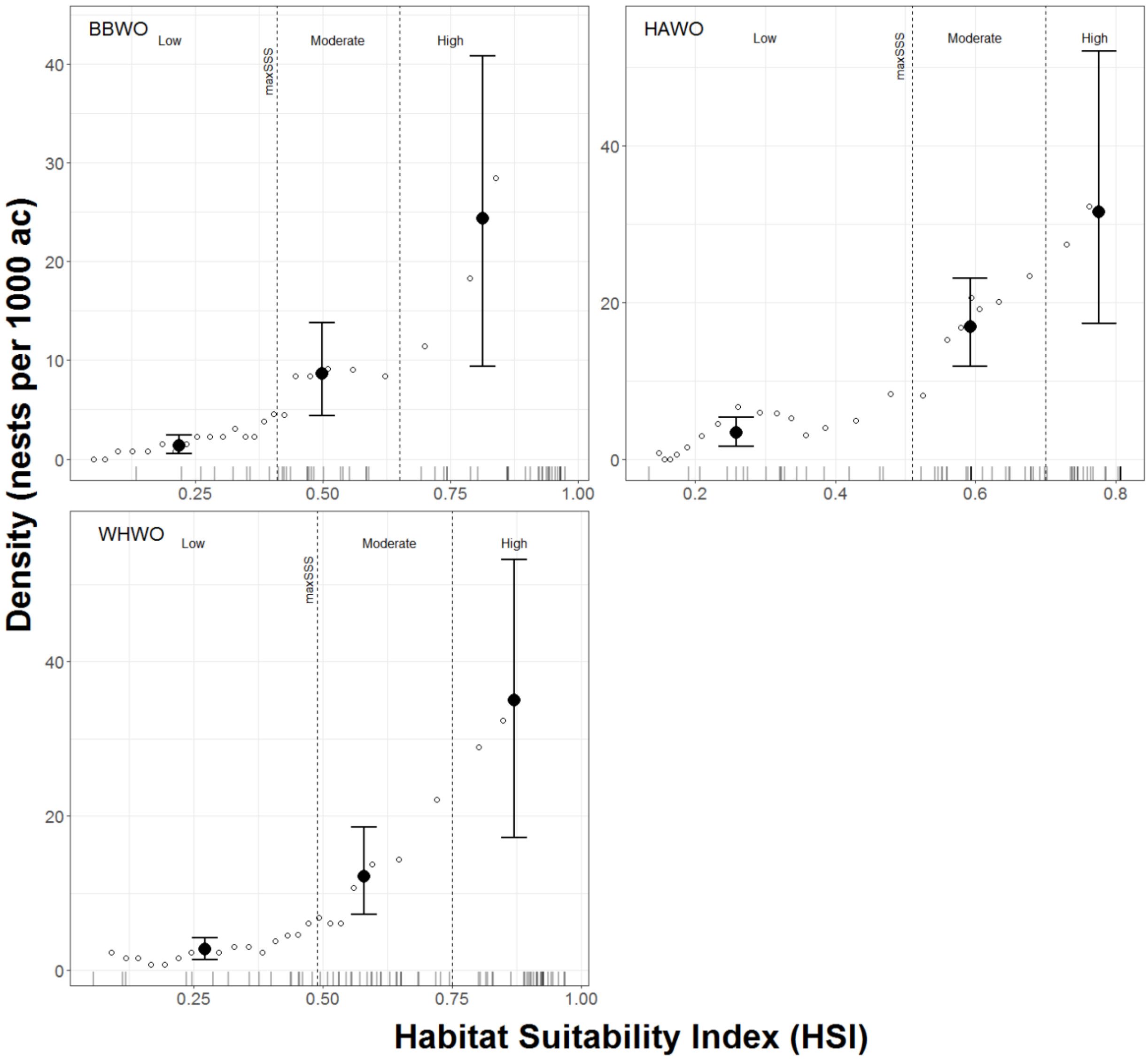


Table 5.1.3. Number of nests and observed nest densities where habitat suitability models were developed for nesting woodpeckers in the Northern Sierra Nevada Mountains by suitability class. Habitat suitability index (HSI) bins define suitability classes. All surveys were conducted within 5 years following wildfire. Expected percent nest values assume observed densities and equal

area surveyed in each suitability categories. Density and percent nest values in parentheses are 95% CLs generated by transect-level boot-strapping (n = 45 transects replicated 5000 times).

Species	Summary quantity	Values by suitability class		
		low	moderate	high
Black-backed Woodpecker	HSI bins	0–0.41	0.41–0.65	0.65–1
	No. nests	8	17	29
	Area surveyed (ac)	5714.3	1976.7	1193.4
	Density (nests per 1000 ac)	1.4 (0.5,2.4)	8.6 (4.3,13.8)	24.3 (9.4,40.8)
	Expected % nests	4 (2,9)	25 (14,45)	71 (49,83)
Hairy Woodpecker	HSI bins	0–0.51	0.51–0.7	0.7–1
	No. nests	18	45	27
	Area surveyed (ac)	5294.1	2678.6	857.1
	Density (nests per 1000 ac)	3.4 (1.6,5.3)	16.8 (11.8,23.1)	31.5 (17.3,52)
	Expected % nests	6 (3,10)	33 (23,47)	61 (45,72)
White-headed Woodpecker	HSI bins	0–0.49	0.49–0.75	0.75–1
	No. nests	16	26	30
	Area surveyed (ac)	5925.9	2148.8	859.6
	Density (nests per 1000 ac)	2.7 (1.4,4.2)	12.1 (7.2,18.6)	34.9 (17.2,53.2)
	Expected % nests	5 (3,10)	24 (16,39)	70 (53,80)

Figure 5.1.3. Observed nest densities (not corrected for detectability) related to habitat suitability index (HSI) values for woodpeckers in the Northern Sierras. Species are Black-backed Woodpecker (BBWO), Hairy Woodpecker (HAWO), and White-headed Woodpecker (WHWO). Small open dots are values for equal-area moving-window bins, and large closed dots are values for suggested HSI suitability categories. Error bars represent 95% CLs generated by transect-level boot-strapping (n = 45 transects replicated 5000 times). Rug plot shows HSI values for nest locations. The low-to-moderate- HSI threshold maximize sum of sensitivity (proportion nests > threshold) and specificity (proportion landscape < threshold; maxSSS).



We recommend managers consider several other factors along with HSI model suitability when planning management of recently burned forests. Studies in Idaho found negative effects of salvage logging on nest density and nest survival for several woodpecker species (Saab et al. 2007). Bark-drilling species, including Black-backed and Hairy Woodpecker, favor and may require nest sites surrounded by relatively high snag densities for foraging (Dudley et al. 2012). Other species, such as White-headed Woodpecker, may forage more in nearby green forest (Wightman et al. 2010). Model HSIs therefore in part reflect forest structure within 1-km of the nest site. Consequently, to safely maintain conditions contributing to suitability of a given patch in their entirety, logging should be restricted within 1 km of that patch even if these surrounding areas are classified as lower suitability. Roadside hazard tree removal can significantly impact burned forest landscapes, especially in areas of high road density. If road closures are not feasible, habitat reserves should be located in areas with minimal road densities, and model applications should account for areas affected by roadside tree removal (e.g., by discounting pre-fire canopy cover input values within affected areas). We generally find woodpeckers nesting in relatively gently sloped areas also favored for salvage logging, so we avoid steep (>30%) slopes when conducting nest surveys. We therefore lack data to fully account for slope in habitat models, but we nevertheless recommend managers favor relatively gentle slopes when identifying where to conserve habitat. Finally, habitat models strictly index nesting densities, so managers may need to consider additional information on other fitness components such as nest survival as is available. In particular, nest survival for Black-backed Woodpeckers in the Inland Northwest and Rocky Mountains can decrease with increasing proximity to unburned edge, possibly reflecting nest predator refugia provided by unburned forest (Saab et al. 2011). Thus, we recommend habitat reserves for this species include a 100 m buffer to insulate core habitat from any adjacent unburned forest.

Disturbance-associated woodpeckers can be highly mobile with populations that persist largely through colonization of newly burned forests mediated by dispersal over large distances (Dixon and Saab 2000, Siegel et al. 2015). Given the importance of dispersal across locations for maintaining populations, habitat targets at any one location should be placed in a landscape context. Thus, we recommend analyzing landscape-scale habitat dynamics and comparing the implications of alternate management scenarios for habitat suitability across entire landscapes to inform conservation objectives for individual projects. In conjunction with tools presented here, development of tools that streamline analysis of landscape-scale habitat dynamics has been funded and is currently underway (National Fire Plan Funded Proposal FY16-FY18; Saab, Latif, and Haas FRF23516). Summaries of observed nesting densities (Tables 5.1.1–5.1.3) provide further context for comparing alternate management scenarios with historically derived benchmarks bearing in mind several caveats:

1. We expect habitat models to be most applicable in unlogged forests to inform planning of subsequent forest management. Given likely negative responses to logging (Saab et al. 2007), we recommend managers initially avoid logging reserves completely and assume nesting will only occur in unlogged reserves in planning documents. In reality, however, woodpeckers will likely make some use of selectively logged forests with potentially similar reproductive success (Saab et al. 2007, Forristal 2009, Saab et al. 2011). Further study may allow precise estimation of population densities with particular treatments and pre-fire conditions. Once available, such information may allow refinement of salvage logging plans to account for more nuanced population responses.
2. Ensemble predictions for Black-backed Woodpeckers not only reflect relative habitat suitability but also modeling uncertainty. Specifically, the moderate suitability classification indicates where there was relatively high disagreement among models, suggesting uncertainty (Latif et al. 2013). Survey units where models were developed included relatively little area classified as moderate suitability, so we are least confident about likely nest densities in moderate suitability areas. In contrast, model disagreement will tend to be higher at locations with environmental conditions that deviate from locations where models were developed (Latif et al. 2013). If a project area is characterized by relatively little highly suitable habitat (e.g., < 15% of area with HSI = 6–

8) but by a larger proportion of moderately suitable habitat (HSI = 3–5), model disagreement is high and we have less confidence in the predictive value of ensemble predictions. For such project areas, monitoring the effects of management treatments and evaluation (and possible refinement) of model predictions with independent data will be needed.

3. HSIs most explicitly describe habitat suitability for nesting but also implicitly contain information on surrounding foraging habitat within 1-km radius neighborhoods. Other studies explicitly quantify foraging habitat, home range size, and relationships between the two (Dudley and Saab 2007, Dudley et al. 2012, Tingley et al. 2014). Remotely sensed data available for most wildfire locations (i.e., burn severity, pre-fire canopy cover) typically lack the resolution for applying published models quantifying foraging habitat suitability. For locations with fine-scale data quantifying snag densities and distributions, home range size and foraging habitat data could inform more informative predictions of population density (e.g., Tingley et al. 2015).

5.2 Guidelines for WHWO in unburned forests

We expect HSIs for nesting White-headed Woodpeckers in unburned forests to primarily inform large-scale forest restoration, e.g., those funded by the Collaborative Forest Landscape Restoration Program (CFLRP; *https://www.fs.fed.us/restoration/CFLRP/*). Managers can limit or defer restoration treatments (usually thinning or prescribed burning for fuels reduction) in areas characterized as high suitability and implement treatments in areas where habitat suitability is limited by a lack of canopy openings (Hollenbeck et al. 2011). Managers could also apply the HSI model to hypothetical landscapes representing projected conditions under alternative management or climate scenarios. HSI maps are posted on the T drive (T:\FS\RD\RMRS\Science\WTE\Research\RMRS-WHWO\Oregon_hsi_maps\WHWO_OR_HSI_maps.gdb) representing conditions in Oregon in 2002 and 2012. As noted above, the model application tool provides for landscapes not adequately covered by these posted layers (e.g., projected future scenarios or landscapes recently affected by disturbance).

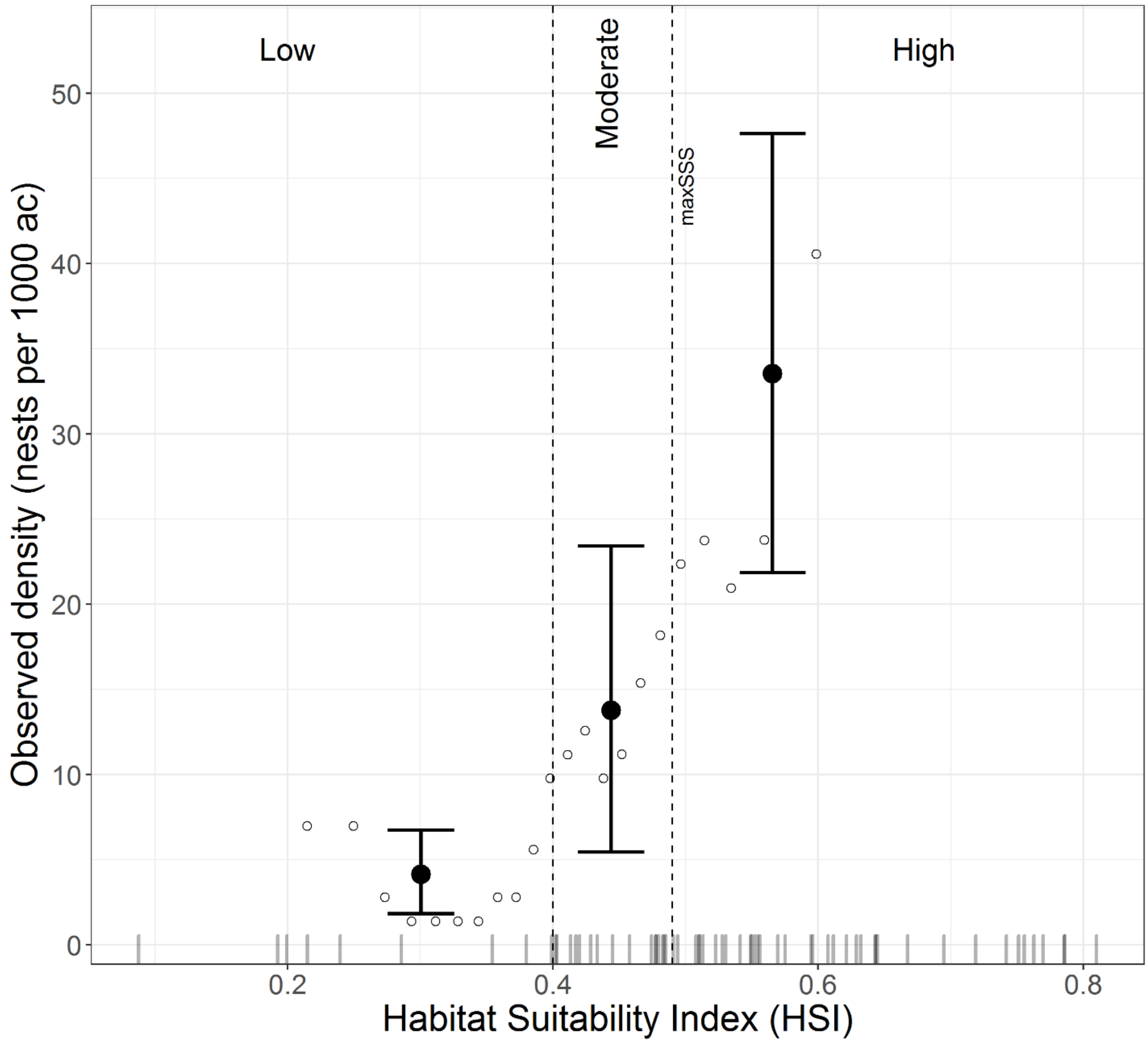
We anticipate forest managers using HSI maps to identify areas where restoration could improve habitat conditions for White-headed Woodpeckers or to evaluate the relative benefits of alterative management strategies. To support such applications, we have identified suitability categories based on HSI relationships with observed nest densities in unburned forests of Oregon (Table 5.2, Figure 5.2). Depending upon specific management goals, we suggest HSI thresholds of 0.4 or 0.49 to distinguish between low, moderate, and high suitability categories. These categories are analogous to those evaluated by Latif et al. (2015), but optimized for the simplified model applied here, such that categories meaningfully differentiate observed densities across multiple national forests representing different geographic regions (Table 5.2). Managers can define alternative suitability categories to accommodate particular objectives by considering how observed nest densities relate with HSIs (Figure 5.2). Managers can then plan or evaluate forest restoration by considering how treatments are likely to affect or have affected the amount and distribution of low, moderate, or high suitability habitat within project areas. Additionally, managers can further gauge the potential implications of treatments for populations by considering observed nest densities at sampled locations (Table 5.2, Figure 5.2).

Table 5.2. Number of nests, area surveyed, and observed nest densities (not corrected for imperfect detection) in habitat suitability categories for White-headed Woodpecker in unburned forests of Oregon. Suitability categories are low (HSI < 0.4), moderate (0.4 ≤ HSI < 0.49), and high (HSI ≥ 0.49). Only nests within 350 m of surveyed transects are represented (i.e., where survey effort was highest and evenly distributed). The model was originally developed with data from the Deschutes and Fremont-Winema National Forests, and data from the Malheur National

Forest were collected following model development. Expected percent nests assume observed densities and equal area surveyed across suitability classes. We boot-strapped data from 57 transects 5000 times at the transect level to generate 95% CLs for all-forest (observed) density and percent nest estimates in parentheses.

National forest	Summary quantity	Values by suitability class		
		low	moderate	high
Deschutes	No. nests	3	4	10
	Area surveyed (acres)	350.4	207.2	291.6
	Density (nests per 1000 acres)	8.6	19.3	34.3
	Expected % nests	14	31	55
Fremont-Winema	No. nests	3	0	4
	Area surveyed (acres)	690.3	267.5	172
	Density (nests per 1000 acres)	4.3	0	23.3
	Expected % nests	16	0	84
Malheur	No. nests	3	12	24
	Area surveyed (acres)	1130.2	622.5	600.9
	Density (nests per 1000 acres)	2.7	19.3	39.9
	Expected % nests	4	31	65
All three forests	No. nests	9	16	38
	Area surveyed (acres)	2175.1	1162.1	1133.4
	Density (nests per 1000 acres)	4.1 (1.8,6.7)	13.8 (5.5,23.6)	33.5 (21.7,47.8)
	Expected % nests	8 (3,15)	27 (12,41)	65 (51,79)

Figure 5.2. Observed nest densities related to habitat suitability index (HSI) values for White-headed Woodpecker in unburned forests of Oregon. Small open dots are values for equal-area moving window bins, and large closed dots are values for suggested suitability categories. Density values are for areas within 350 m of transects where survey effort was highest and evenly distributed. Error bars represent 95% CLs generated by transect-level boot-strapping (n = 57 transects replicated 5000 times). Rug plot shows HSI values for nest locations (n = 63). The moderate-to-high HSI threshold (0.49) maximizes the sum of sensitivity (proportion nests classified high) and specificity (proportion landscape classified low or moderate; maxSSS).



The HSI model presented here should be applied outside Oregon with caution, particular in landscapes with conditions that differ substantially from those where models were developed (see Latif et al. 2015). For example, we facilitated application of this model to inform sampling design for monitoring White-headed Woodpecker at the Nez Perce-Clearwater National Forest in Idaho. The model assigned extremely low HSI values to most areas because the Idaho study area was characterized by much greater topographic relief than Oregon study areas. An alternate model fitted to available data that excluded topographic predictors (i.e., Slope and Cosine

Aspect; Table 2.2) appeared more useful and may be added to the GIS toolbox described here following evaluation with independent data in Idaho.

When using HSIs to inform conservation or restoration, environmental inputs used to calculate HSIs need careful consideration. HSIs are calculated in part using variables representing forest structure over a 1-km radius area (Table 2.2), so management decisions need to include areas within 1 km of target locations. Additionally, evaluating whether suitability at potential project areas is mainly limited by the arrangement of open- and closed-canopy forests or by the absence of ponderosa pine within 1 km of these areas is necessary to inform restoration treatments. We expect restoration treatments to have greater potential to primarily improve habitat suitability in the near term by encouraging canopy mosaics, but treatments could also benefit habitat suitability in the long term if they encourage ponderosa pine dominance. To best inform their decisions, forest managers should ideally compare HSI maps generated for landscapes explicitly representing projected results of alternative management options.

We did not attempt to relate HSIs with observed nest densities. Anticipated uses of this HSI model will focus on relative differences in amount of suitable habitat under alternative scenarios rather than determining an absolute amount of habitat to conserve. Effectiveness monitoring studies of CFLR treatments are generating data for evaluating treatment effects on White-headed Woodpecker nesting densities and habitat.

6. CONCLUSIONS AND FUTURE DIRECTIONS

Despite widespread development of models intended to inform habitat management, accessibility limits their application (Guisan et al. 2013). The tools described here are designed to improve accessibility of habitat suitability models for disturbance-associated woodpeckers to help inform forest management in western North America. Our approach consists of integrating model application tools into software commonly used for management planning (ArcGIS) and providing guidelines for interpreting HSI maps in relation to underlying species ecology.

Thus far, we provide model application tools for woodpecker species of conservation concern for various management activities occurring in conifer forests. Several woodpecker species inhabit forests recently burned by wildfire, for which habitat models can strongly inform post-fire salvage logging activities. Additionally in the Inland Northwest, the White-headed Woodpecker specializes on ponderosa pine-dominated forests characterized by canopy mosaics, wherein habitat models for unburned forests could inform large-scale forest restoration treatments.

Although we expect these model application tools to broadly inform management of conifer forests, incorporating additional models would be desirable. For example, habitat models for Lewis's Woodpeckers (*Melanerpes lewis*) in burned forests would further inform salvage planning. Black-backed, White-headed, Hairy, and Lewis's Woodpeckers use a range of habitat conditions for nesting within burned forests, such that managing for multiple woodpecker species will likely result in conditions beneficial for a variety of other species (Saab et al. 2009, Saab et al. 2011). Following further development and refinement of habitat suitability models for woodpeckers and other species adapted to disturbance-maintained forests, additional application tools will be incorporated into this series.

This series of application tools is currently geared to habitat conservation for woodpeckers nesting in dry conifer forests, although we expect the approach could be more broadly applied. We anticipate additional model application tools that will facilitate broader use of habitat models for a variety of species to inform management decisions and plans.

7. ACKNOWLEDGEMENTS

We thank….

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9. APPENDICES

9.1 Appendix A – RAVG-based models to support planning immediately following wildfire

Habitat models for burned forest in the Inland Northwest were originally developed with burn severity data available under the [Monitoring Trends in Burn Severity (MTBS)] program for U.S. wildfires from 1984 onward. MTBS provides standardized and ecologically relevant data for monitoring wildfire trends and patterns in ecosystems in slow-growth systems, such as forests, by contrasting pre-fire satellite imagery with imagery recorded one year post-fire during the growing season (i.e., *extended assessment*). These data are particularly relevant for quantifying woodpecker habitat in burned forest because the timing of post-fire imagery is suited to reflect the substantial tree mortality (and snag generation) in the first year following wildfire. Post-fire forest planning is often initiated well before MTBS data become available, however. To support more immediate analysis needs, burn severity data based on an *immediate assessment* (within 45 days following wildfire containment) are also available for wildfires on NFS lands through the [Rapid Assessment of Vegetation Condition after Wildfire (RAVG)] process.

We initially developed models using MTBS burn severity data for Black-backed and White-headed Woodpecker in burned forests of the Inland Northwest because of their ecological relevance. Recognizing the need for rapid assessment for post-fire planning, however, we provide here alternate versions of these models based on RAVG data. We fitted alternate models with RAVG-derived burn severity variables (see Tables 2.1, 2.3.2). Thus, RAVG HSI models are structured the same as original MTBS-based models, but coefficient values instead reflect nesting relationships with RAVG burn severity. Tools for obtaining HSI maps from RAVG-based models are operated as follows:

1. Obtain RAVG-based burned severity data following Step I.A under Section 4.4 apply input development instructions (Step I.A in Sections 4.1 and 4.3).
2. Apply input development tools using the RAVG (instead of MTBS) dNBR (I.B–C in Sections 4.1 and 4.3).
3. Apply RAVG versions of model application tools with resulting inputs. Navigate to "TOOLBOX →Habitat Suitability Modeling.tbx → HSI models", and locate the "Black-backed Woodpecker (RAVG)" and/or "White-headed Woodpecker Burned (RAVG)" tools. Then follow instructions under Step III, Section 4.1 and/or Step II, Section 4.3, respectively, to operate these tools.

To support application of RAVG-derived HSI maps where needed, we related RAVG HSIs to nest densities and compare MTBS versus RAVG HSIs. For both species, nest densities were sufficiently related with RAVG-based HSIs to inform management (Tables 9.1.1, 9.1.2, Figures 9.1.1, 9.1.2). Considering these relationships, we modified HSI thresholds for RAVG-based BBWO HSI models for classifying low, moderate, and high suitability habitat (Table 9.1.1, Figure 9.1.1). For WHWOs, we recommend the same thresholds for RAVG HSI models also identified for MTBS models (Table 9.1.2, Figure 9.1.2). We compare MTBS to RAVG HSIs at three wildfires that burned in 2015 in Oregon and Washington (Figure 9.1.3). RAVG HSIs and suitability classifications were strongly correlated with original MTBS versions for both species at all three locations (Table 9.1.3). Consequently, RAVG and MTBS HSI models identified similar areas as suitable (e.g., Figure 9.1.4).

Table 9.1.1. Observed nest densities (per 1000 ac) at model development locations for nesting Black-backed Woodpeckers. Low, moderate, and high suitability classes correspond with alternate RAVG-based ensemble model predictions of 0–2, 3–6, and 7–8, respectively. Percent nests = the expected value given even sampling across categories. Area surveyed represents the

extent surveyed each year multiplied by study duration at each location. 95% confidence limits (error bars) were bootstrapped using 600 m cells as sampling units (n = 67, 83, and 176 for Star Gulch, Tripod, and Toolbox locations, respectively).

Location	Quantity	Habitat suitability (HSI) class		
		Low	Moderate	High
Star Gulch	Density	0.22 (0,0.56)	2.07 (0.32,4.51)	3.92 (2.55,5.35)
	Percent nests	4 (0,10)	33 (7,54)	63 (45,89)
	Area surveyed (ha)	6398	5714.2	6665
Tripod	Density	0 (0,0)	1.96 (0,4.72)	9.86 (4.3,16.1)
	Percent nests	0 (0,0)	17 (0,43)	83 (57,100)
	Area surveyed (ha)	4637	1353.8	1643.1
Toolbox	Density	1.28 (0.41,2.26)	5.92 (3.41,8.84)	11.03 (8.38,13.93)
	Percent nests	7 (2,12)	32 (21,44)	61 (49,73)
	Area surveyed (ha)	4279.2	3693	6363.8
All[a]	Density	0.31 (0.06, 0.66)	3.17 (2.06, 4.43)	7.63 (6.09, 9.24)

[a]Values represented in Figure 9.1.1.

Figure 9.1.1. Observed nest densities related to alternate RAVG-based ensemble habitat suitability index (HSI; i.e., the number of models classifying a given site suitable) for Black-backed Woodpeckers in the Inland Northwest. Small black dots are values for individual HSI levels. Large red dots represent observed densities averaged (mean) across locations (Star Gulch, Toolbox, and Tripod) within suitability categories (low, moderate, and high) and are plotted at mean HSI values. 95% confidence limits (error bars) were bootstrapped using 600 m cells as sampling units (n = 326 across all three locations).

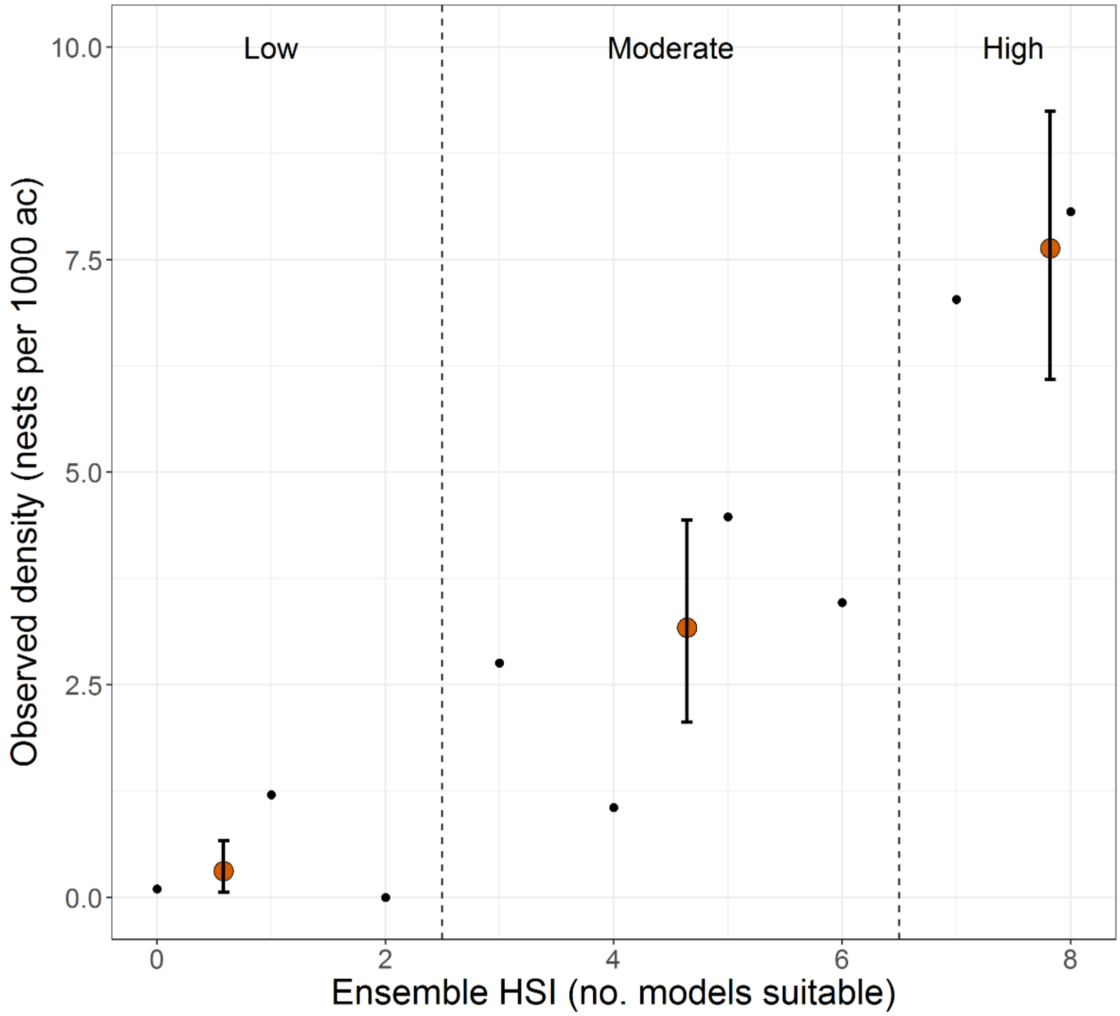


Table 9.1.2. Density of hatched nests (per 1000 ac) in suitability classes defined by alternative RAVG-based HSI model thresholds (0.34, 0.6) for White-headed Woodpeckers in burned forest. Models were developed at Toolbox and Canyon Creek wildfire locations (Oregon). 95% CLs (in parentheses) were generated with non-parametric bootstrapping. Values for "percent nests" are the expected percent of hatched nests assuming equal area sampling across suitability classes. Area surveyed was calculated as the proportion of sites representing the surveyed area in each suitability class multiplied by the total area surveyed at each location.

Location	Quantity	Habitat suitability (HSI) class		
		Low	Moderate	High
Toolbox	Density	0.31 (0.1,0.57)	1.24 (0.66,1.85)	4.43 (2.57,6.58)
	Percent nests	5 (2,10)	21 (11,33)	74 (60,84)
	Area surveyed (ac)	19319.2	12857.2	4961.6
Canyon Creek	Density	0.8 (0.36,1.34)	3.05 (1.84,4.3)	8.41 (4.4,13.27)
	Percent nests	7 (3,12)	25 (14,40)	69 (51,81)
	Area surveyed (ac)	13773.6	7220.9	1427.1
Both[a]	Density	0.51 (0.28,0.77)	1.91 (1.32,2.55)	5.33 (3.57,7.25)

[a]Values represented by red circles and error bars in Figure 9.1.2.

Figure 9.1.2. Densities of hatched nests for White-headed Woodpeckers along alternate RAVG-based habitat suitability index (HSI) gradient in burned forest. Low, moderate, and high suitability classes are differentiated by two HSI thresholds, one that maximizes the sum of sensitivity and specificity (maxSSS) and the other placed at a natural break in densities for equal-area moving window bins in this figure (small dots) and the distribution of nest site HSIs (rug bars). Large circles and error bars are density estimates and bootstrapped 95% CIs for habitat suitability classes.

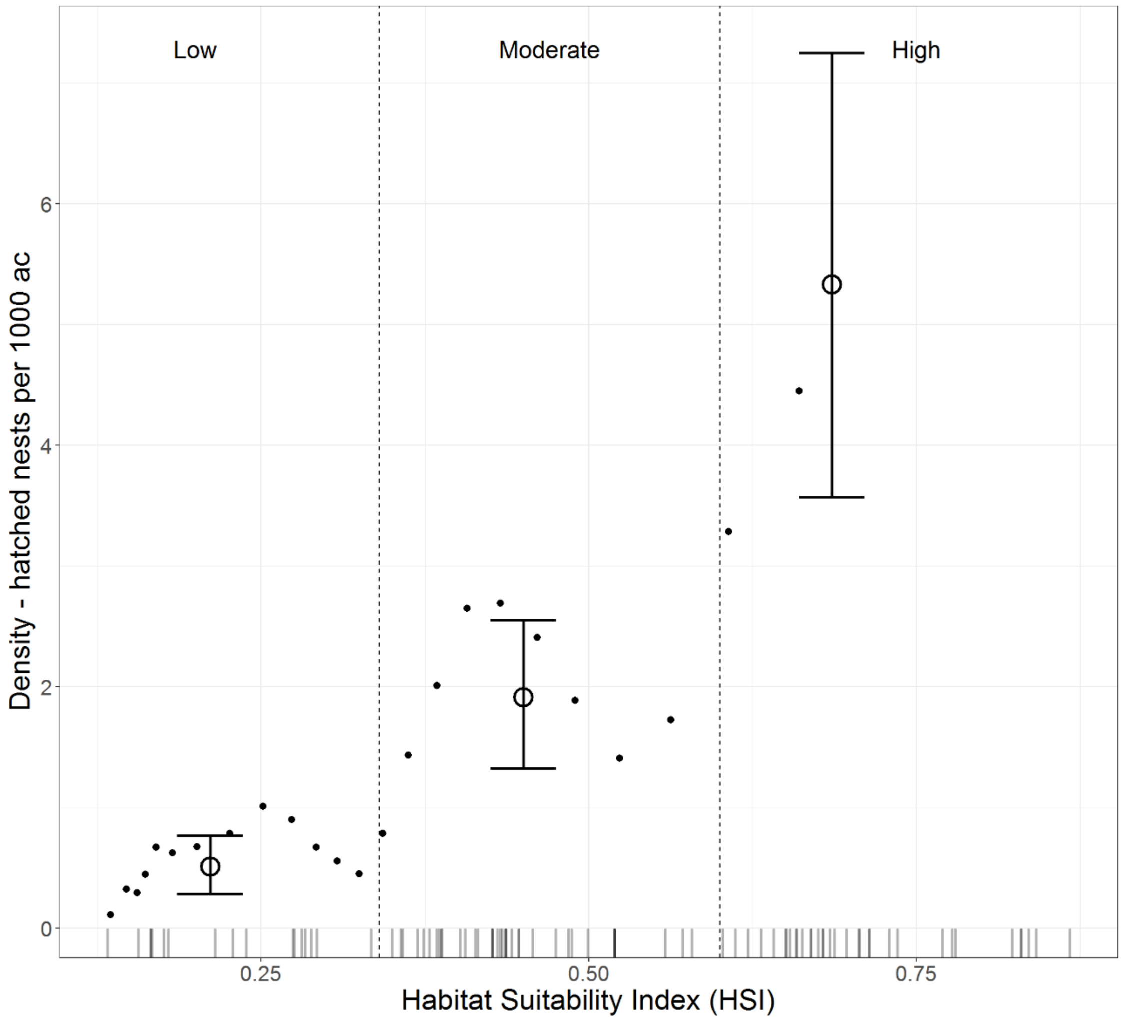


Figure 9.1.3. Three wildfires that burned in Oregon (Cornet-Windy Ridge, Canyon Creek) and Washington (North Star) in 2015 where we compared MTBS- to RAVG-based HSIs for Black-backed and White-headed Woodpecker.

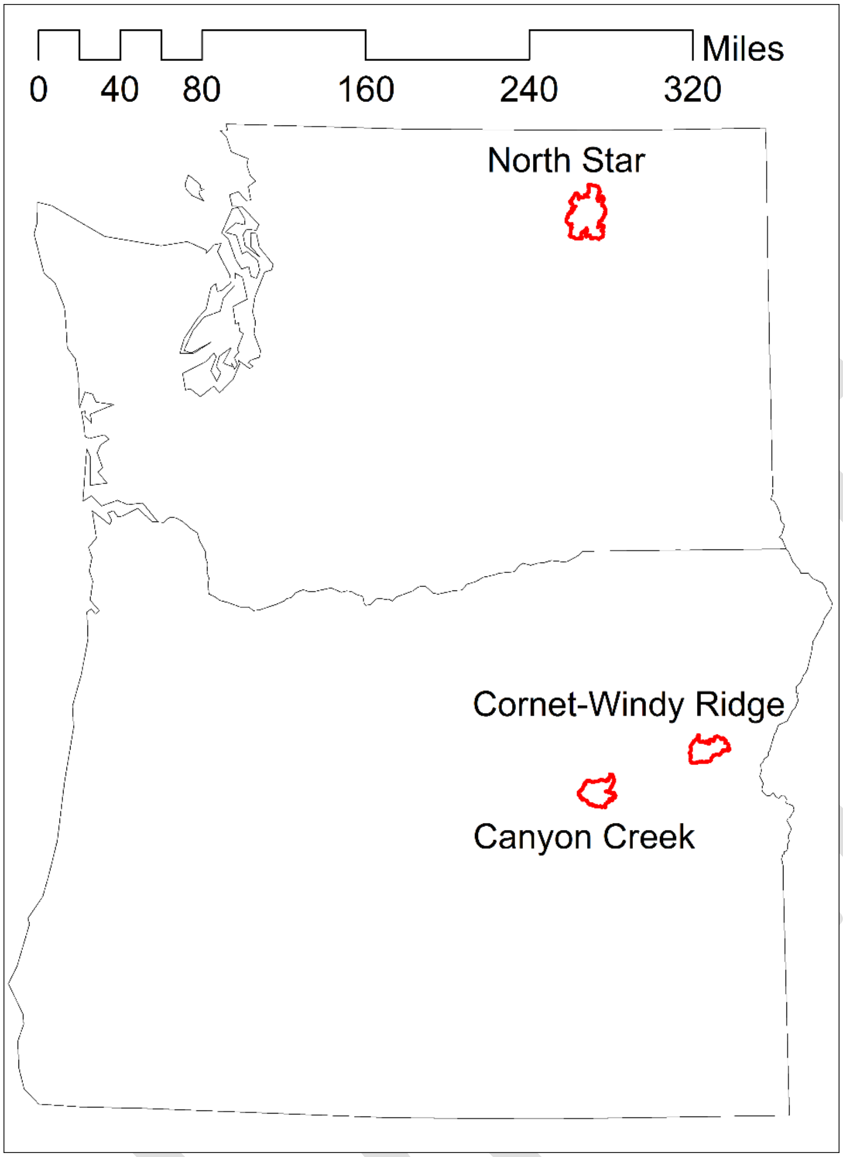
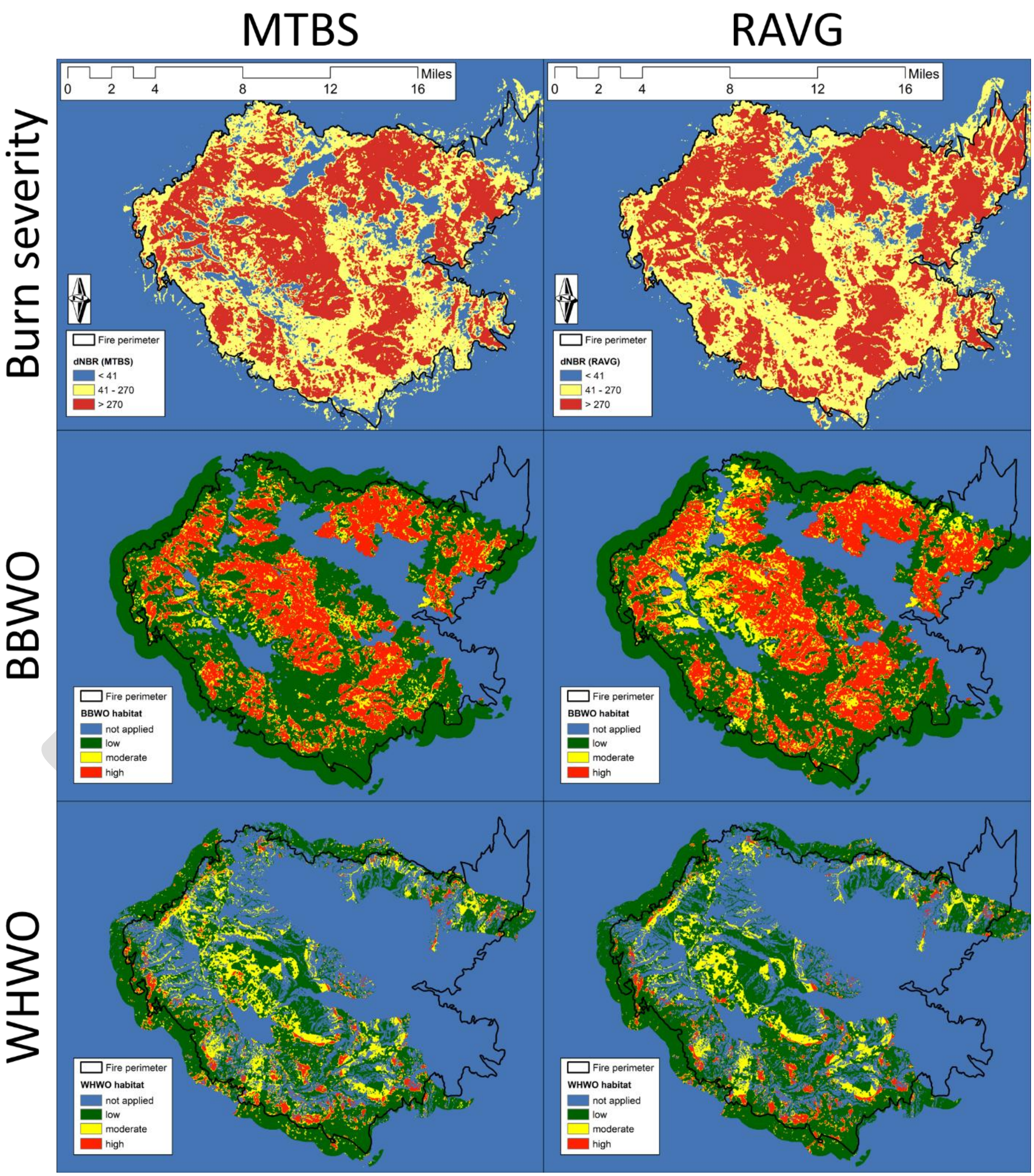


Table 9.1.3. Correspondence between original (MTBS-based) and alternative (RAVG-based) HSI models at three 2015 wildfires in Washington (North Star) and Oregon (Canyon Creek, Cornet-Windy Ridge). Correlation coefficients (Pearson's *r*) relate continuous HSI values for 30-m pixels. The percent of pixels classified the same (low, moderate, or high suitability) using recommended MTBS- versus RAVG-based HSI thresholds are also reported.

Location	Pearson's *r*		% consistently classified	
	BBWO	WHWO	BBWO	WHWO
North Star	0.689	0.576	62	70
Canyon Creek	0.852	0.814	74	81
Cornet-Windy Ridge	0.762	0.716	69	74
All	0.741	0.7	66	75

Figure 9.1.4. Burn severity (top row) and HSI maps (bottom two rows) for Black-backed (BBWO) and White-headed Woodpecker (WHWO) at the Canyon Creek Fire (Oregon, 2015). Versions derived from Monitoring Trends in Burn Severity (MTBS) versus Rapid Assessment of Vegetation Condition after Wildfire (RAVG) are compared. HSI maps are masked to exclude areas outside the range of conditions where models were developed.



Consistent with our expectations given the ecological relevance of MTBS burn severity, nest densities related more closely with MTBS than RAVG HSIs (compare Tables 9.1.1, 9.1.2 and Figures 9.1.1, 9.1.2 with Tables 5.1.1, 5.1.2 and Figures 5.1.1, 5.1.2, respectively). We therefore recommend using MTBS-based models when possible for Black-backed and White-headed Woodpecker in the Inland Northwest, but offer RAVG-based alternatives to support planning needs following wildfire but before MTBS data become available.

9.2 Appendix B – Demonstration of model application to inform post-fire management planning

We demonstrate here how habitat suitability models for disturbance-associated woodpeckers could inform planning of burned forest management using the Canyon Creek Fire (Oregon, 2015) as a case study. We consider a hypothetical scenario wherein managers have identified a series of 6 potential management units with opportunity for salvage logging (Figure 9.2.1). The units considered here were actual management units identified during the post-fire planning process at Canyon Creek, and treatment units are the areas within management units where salvage logging was possible and implemented (given slope, accessibility, and economic viability). Thus, these units are realistic, but we constructed a simplified decision scenario purely to demonstrate how HSI models could inform post-fire planning.

We assume a minimum sale area of 700 ac for economic desirability for salvage logging given contemporaneous market conditions. We also assume biologists have identified a maximum of 50 breeding pairs whose nest sites can be impacted by logging (i.e., occur within logged areas) without violating legal mandates for species conservation. We assume these targets were developed from a regional assessment of current population status. For the sake of simplicity, we focus this scenario on just one woodpecker species, the Black-backed Woodpecker, with clearly documented negative relationships with logging (Saab et al. 2007). We consider both potential effects on nesting habitat within treated areas and on foraging habitat for nests within 1 km of logged areas. We used HSI models based on MTBS data to inform planning in this scenario, but the principles demonstrated here would also be relevant to RAVG-based HSI model application. The HSI map relevant to this scenario is shown in Figure 9.1.4 (middle row, left column), and nest density relationships with modeled suitability are in Table 5.1.1 and Figure 5.1.1.

Scenario options where 4 of 6 management units were included in the logging sale unit met our hypothetical economic benchmark of 700 ac treated. Of these, the upper 95% CL for potential nest numbers affected fell below our maximum allowable of 50 for six options (Table 9.2.1). Assuming timber volume (and consequent economic desirability) for a given sale are related to the area treated, scenarios B and E appear most desirable. Of these, the number of nesting pairs whose foraging or nesting habitat could be affected (i.e., the 1-km radius footprint for treatment areas), was smaller for option B. Thus, option B was most desirable to meet the multiple objectives and criteria defined in our hypothetical scenario.

Our hypothetical planning scenario ignores several realities likely facing managers engaged in post-fire forest planning. We focused only on one woodpecker species, whereas multiple species will likely be of concern, including those not necessarily represented in our toolset (e.g., Lewis's Woodpecker), for which other tools may be needed to identify suitable habitat. We considered economic viability of salvage logging units in terms of the potential area treated, whereas managers would instead likely quantify timber volume, which may not correlate perfectly with area treatable. We ignored roadside hazard tree removal, which was extensive at the Canyon Creek Fire. With the high prioritization of human safety, roadside treatments may be non-negotiable, in which case assessments of impacts to woodpeckers should account for hazard tree removal. With all these consideration, post-fire forest planning will be substantially more complicated than depicted in our example. Nevertheless, we expect this demonstration to be useful for showing how to apply HSI maps and HSI-related nest densities to inform the planning process.

Figure 9.2.1. Potential units considered in a hypothetical post-fire management scenario for the Canyon Creek Fire (Oregon, 2012). Scenario options entail subjecting different combinations of management units to salvage logging. Treatment units are the areas within management units with opportunity for logging.

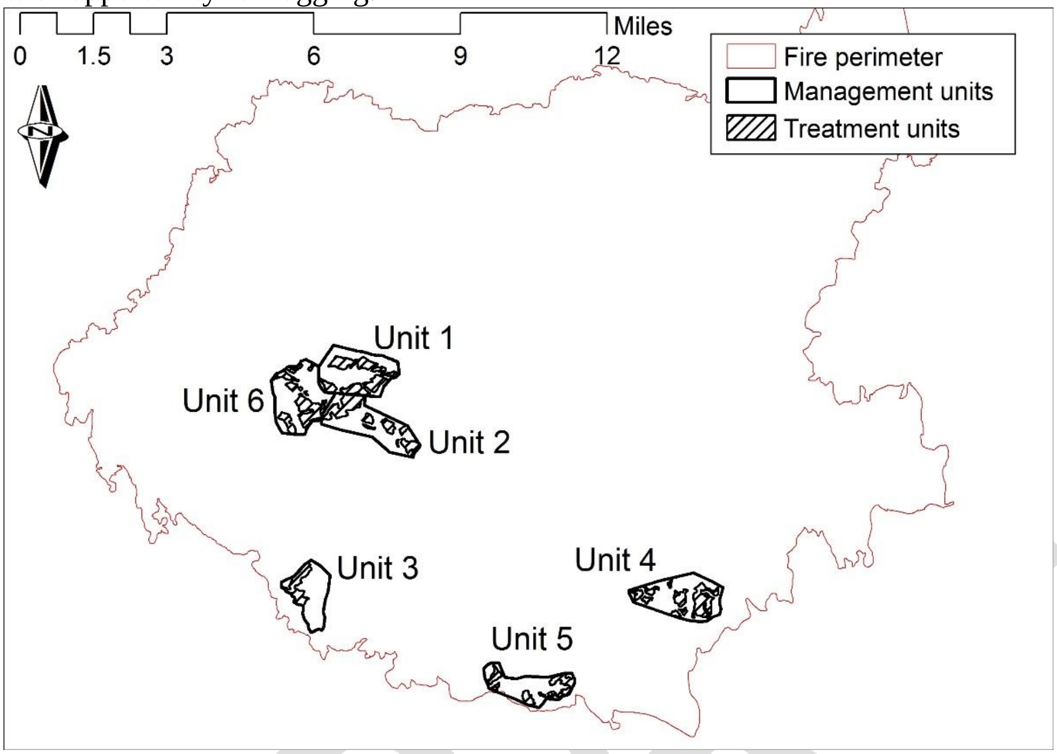


Table 9.2.1. Alternative options consisting of different combinations of management units selected for post-fire salvage logging at the Canyon Creek Fire (Oregon, 2015). Unit numbers correspond with those in Figure 9.2.1. Black-backed Woodpecker (BBWO) habitat is the sum of moderate and high suitability areas, and potential nests (and 95% boot-strapped CLs) were estimated assuming similar densities to those observed at HSI model development locations (see Figure 5.1.1). When calculating potential nest numbers, densities were multiplied by 5 to reflect assumed viability of BBWO habitat for 5 years following wildfire and development of HSI models within this timeframe. Values for "treated" represent the total area actually logged. Values for "affected" represent the area within 1-km of logging, within which nesting pairs could experience reduced foraging opportunities due to logging.

Option	Units treated	Area (ac)		BBWO habitat (ac)		Potential BBWO nests	
		treated	affected	treated	affected	treated	affected
A	1, 2, 3, 5	752.1	9576.2	595.6	4735.9	34 (23,45)	262 (175,359)
B	1, 2, 3, 6	839.1	8187.6	655.4	4396.3	36 (24,49)	239 (160,327)
C	1, 3, 5, 6	750.8	9549.5	647.2	4508.8	36 (24,48)	247 (165,340)
D	2, 3, 4, 5	722.1	11131.5	597.5	5149.3	34 (23,46)	286 (190,393)
E	2, 3, 4, 6	809.1	10238	657.4	5075.1	36 (24,49)	277 (184,380)
F	2, 3, 5, 6	733.7	10128.8	582	4437.2	31 (21,43)	239 (157,330)
G	3, 4, 5, 6	720.7	11020.2	649.2	4684.6	36 (25,49)	256 (168,354)

9.3 Appendix C – Troubleshooting guide

Problem C1. – When attempting to retrieve RAVG burn severity data for my project area, the data retrieval window is not visible on the website as shown in the instructions (Section 4.4).

Solution C1. – You may not have Adobe Flash Player installed or enabled. Search for "install or enable Adobe Flash Player" on the internet to find instructions to install, enable, and check the status of Adobe Flash Player. If Adobe Flash Player is enabled but the online data retrieval tool remains unavailable, you can contact the RAVG program directly via email or via their website.

Problem C2. – I received an error when attempting to run one of the input generation tools for Black-backed or White-headed Woodpeckers in burned forests of the Inland Northwest (e.g., `Failed to execute (BBWOINPUTS).`).

Solution C2.1. – If the error notification indicates that default layers on the T drive were not found, try closing and reopening the tool, and rerunning.

Solution C2.2. – The wildfire perimeter may fall outside the spatial extent where default data are available. You may need to truncate the fire perimeter shapefile to only include areas where default data are available, or develop model inputs manually (see I.C in Section 4.1 or 4.3). You can view default canopy cover and topography data at: T:\FS\RD\RMRS\Science\WTE\Research\HSI_applic_tool\PA_RASTERS.

Solution C2.3. – The extents of burn_bndy.shp and dnbr.tif files may not match. Make sure the two files are for the same fire, and check to make sure the coordinate systems are correctly specified for both files.

Problem C3. – When attempting to operate the input generation tool for the Northern Sierras, I receive errors that resemble the following:

```
Error: "000732: <value>: Dataset <value> does not exist or is not
supported."

ExecuteError: Failed to execute. Parameters are not valid.
ERROR 000732: Input Features: Dataset '…' does not exist or is not
supported
Failed to execute (PolygonToRaster).
```

Solution C3. – Check the folder names and pathways for input files. Filenames and pathways should contain no spaces. In particular, the most likely reason for this error is an invalid path name for Existing Vegetation polygons downloaded from the Region 5 website. If the file geodatabase containing the polygons is embedded within a file of the same name, you will receive this error. For example, these paths result in an error:

> C:\GIS\vegetation\eveg\ExistingVegR5_SouthSierra1995_2016_v1.gdb\ExistingVegR5_SouthSierra1995_2016_v1.gdb\ExistingVegR5_SouthSierra1995_2016_v1

C:\GIS\vegetation\Existing Veg\ExistingVegR5_SouthSierra1995_2016_v1.gdb \ExistingVegR5_SouthSierra1995_2016_v1

But this path is acceptable:

C:\GIS\vegetation\eveg\ExistingVegR5_SouthSierra1995_2016_v1.gdb\ExistingVegR5_SouthSierra1995_2016_v1